MMR Doc. No.
12627

Massachusetts Military Reservation

PLUME RESPONSE PROGRAM

Final
Fuel Spill-12 Treatment System
1998 Annual Ecological Assessment Report

December 1999

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Document No.: AFC-J23-35S18901-M21-0010

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TABLE OF CONTENTS

TABLE OF CONTENTS

Figures

Tables

Appendices

ACRONYMS AND ABBREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
ANG	U.S. Air National Guard
ARNG	Massachusetts Army National Guard
AVGAS	aviation gasoline
° C	degrees Celsius
cells/ml	cells per milliliter
CLP	EPA Contract Laboratory Program
COPEC	chemical of potential ecological concern
CS-10	Chemical Spill-10
DEP	Massachusetts Department of Environmental Protection
DIC	dissolved inorganic carbon
DO	dissolved oxygen
DOC	dissolved organic carbon
ECG	ecological criteria guideline
EDB	ethylene dibromide
EPA	U.S. Environmental Protection Agency
ETR	extraction, treatment, and reinjection system
° F	degrees Fahrenheit
FS-12	Fuel Spill-12
ft	feet
ft^3/day	cubic feet per day
gpm	gallons per minute
Ho	null hypothesis
JP	jet petroleum

LCL	95 percent lower confidence limit
LSD	least significant difference
MA	Massachusetts
max	maximum value observed
MCL	maximum contaminant limit
$\mu g/L$	micrograms per liter
$\mu S/cm$	microsiemens per centimeter
mg/L	milligrams per liter
MMR	Massachusetts Military Reservation
mi^2	square miles
min	minimum value observed
msl	mean sea level
mV	millivolts
n	number of observations
NA	not applicable
ND	nondetect
ntu	nephelometric turbidity units
NYDEC	New York State Department of Environmental Conservation and Federation of Lake Associations, Inc
organisms/cm^2	organisms per square centimeter
ORP	oxidation reduction potential
Op Tech	Operational Technologies Corporation
PME	performance monitoring evaluation
QPP	Quality Program Plan
SC	specific conductance

sd	standard deviation
SD-5	Storm Drain-5
SSC	species of special concern
TAL	target analyte list
TCL	target compound list
TDS	total dissolved solids
TOC	total organic carbon
TRET	Technical Review and Evaluation Team
TSI	trophic state index
TSS	total suspended solids
UCL	95 percent upper confidence limit
USAF	U.S. Air Force
USCG	U.S. Coast Guard
VA	Veterans Administration
VOC	volatile organic compound
WL	watch list

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EXECUTIVE SUMMARY

This report presents the 1998 annual evaluation of ecological receptors downgradient of the Fuel Spill-12 (FS-12) extraction, treatment and reinjection (ETR) system which is used to treat known plume contaminants in the FS-12 plume. The assessment, conducted by the Ecological Studies Program at the Massachusetts Military Reservation (MMR) on Cape Cod, Massachusetts, compared conditions before the plant began operating (Phase I) to conditions after plant operations began (Phase II). The investigation evaluated the ecosystems of Snake Pond, Peters Pond, Weeks Pond, and Triangle Pond. Water levels, water chemistry, and biological resources were assessed to assure that the ETR system was not adversely affecting the downgradient ecosystems. This report represents a summary analysis of 1998 annual chemical and physicochemical data. This report also includes the laboratory analytical data for the Fall 1998 sampling round.

The groundwater study at FS-12 included examination of upgradient, downgradient, and reference groundwater. An analysis was performed for Tier I parameters: water level, temperature, pH, dissolved oxygen (DO), and dissolved organic carbon (DOC). One of the Tier I parameters, DOC, exceeded ecological criteria guidelines for Phase II. Ecological criteria guidelines are values used to assess levels of change in an ecosystem by comparing proportional changes between potentially impacted (study) ecosystems and reference ecosystems and determine acceptability. The downgradient groundwater had significantly lower DOC concentrations than the reference groundwater. If this is attributable to the ETR, because the ETR removes DOC prior to reinjection, it is not considered a potential adverse affect. The removal of organic contaminants from the groundwater is the goal of the ETR system, and lower concentrations of DOC in downgradient groundwater are desirable because this implies that the ETR is performing appropriately.

Groundwater samples collected for 1998 were screened against drinking water standards (DEP 1997) for chemical and physicochemical parameters (Appendix H-1). A primary concern is an exceedence of EDB in Snake Pond microwell

ECMWSNP02D of 0.029 μg/L from a sample collected in November. This exceedence may indicate that some plume contaminants were not captured by the FS-12 ETR system and were transported into the downgradient groundwater. The microwells in Snake Pond exhibited several exceedences for total metals (iron and nickel). The upgradient well 90MW0020 showed exceedences of plume contaminants EDB and benzene. The upgradient well also had drinking water exceedences for iron and manganese.

The surface water investigation for the FS-12 ETR ecological monitoring concentrated on Snake Pond and two reference ponds, Peters and Triangle ponds. The analysis of pond water levels showed that there were no exceedences in mean pond elevation for either the study pond or reference ponds. There were no surface water Ecological Criteria Guideline exceedences in Tier I parameters (temperature, pH, DO, and DOC) for Phase II.

A water quality screen was performed for Ecotox threshold (EPA 1996) on surface water samples (collected in 1998) at Snake Pond, Peters Pond, and Triangle Pond. There were two exceedences of Ecotox thresholds for barium (3.9 μg/L) at Snake Pond. There were no Ecotox threshold exceedences at other surface water sampling locations.

The results observed in the Phase I and Phase II phytoplankton and zooplankton communities indicated that differences were the result of changes in climatic conditions and sampling strategies. Because similar results were observed in both the study and reference ponds, the differences between the 1996-1997 and 1998 phytoplankton and zooplankton communities were not attributed to the operation of the FS-12 groundwater treatment system. There was an ecological criteria guideline exceedence for Phase II chlorophyll *a* measurements between Snake Pond and the reference ponds. This exceedence was attributed to a decrease in chlorophyll *a* in the reference areas in comparison to Snake Pond. Chlorophyll *a*, a Tier II parameter, was

more stable in Snake Pond in comparison to the reference ponds. This exceedence was not attributed to the FS-12 ETR system.

The order Diptera dominated the benthic macroinvertebrate community in all ponds in 1997 (Phase I) and 1998 (Phase II). The benthic macroinvertebrate concentrations did exceed a Tier II ecological criteria guideline. There was a greater than 20 percent difference between the concentrations in Snake Pond in comparison to the reference ponds in Phase II. Statistical analyses showed that there was no significant difference and the season in which the sample was collected had the most significant effect on the variability in the data set. The statistical analyses of the data indicated the benthic macroinvertebrate community was not affected by the operation of the FS-12 groundwater treatment system.

The vegetation around Snake Pond has been affected by a water table that was 5 feet higher in 1998 than water levels recorded in 1996. This elevated water level has resulted in a reduction of estimated cover class for herbaceous plants and the death of pitch pine *(Pinus rigida)* seedings. The elevated water levels have also promoted an increase in more hydrophyllic vegetation such as highbush blueberry (*Vaccinium corymbosum*), sweet pepperbush (*Clethra alnifolia*), and meadowsweet (*Spiraea latifolia*). This high water table is representative of a natural fluctuation in water levels common in the area. Leaves of slender arrowhead (*Sagittaria teres*), a species of special concern, were observed at Snake Pond and Triangle Pond. Watch list plant species recorded in the surveys were hyssop hedge-nettle (*Stachys hyssopifolia*) and annual umbrella sedge (*Fuirena pumila*). No state-listed animals were recorded at any of the ponds.

The investigation concluded that the FS-12 ETR system is not having any adverse affect on the downgradient ecosystems.

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1.0 INTRODUCTION

The U.S. Air Force is implementing cleanup activities to address contaminated groundwater that has resulted from past military activities at the Massachusetts Military Reservation (MMR) on Cape Cod. Ecological assessments are being conducted to evaluate the potential for undesirable ecological impacts resulting from the extraction of contaminated water or the addition of treated water from treatment systems operated to remediate groundwater plumes. Work was performed under contract number F 41624-97-D-8006-0003.

This report represents a summary analysis of 1998 annual chemical and physicochemical data. This report also includes the laboratory analytical data for the Fall 1998 sampling round. This document presents an assessment of impacts on surrounding ecosystems from the Fuel Spill-12 (FS-12) extraction, treatment, and reinjection (ETR) system from July, 1996 through December, 1998. The ETR system is a network of wells that extract groundwater, treat it to reduce or eliminate contaminants, and reinject the treated water to the aquifer. The FS-12 ETR system commenced operation September 18, 1997.

This report is presented in support of the Air Force Center for Environmental Excellence (AFCEE) Installation Restoration Program at the MMR on Cape Cod (Figure 1-1). The history of this military base, the groundwater plumes and their description, and the strategy for the ecological monitoring program are provided in the *Final Work Plan for the Ecological Assessment Associated with Groundwater Plumes and Remedial Activities* (AFCEE 1998c). The work plan and the *Final Fuel Spill-12 (FS-12) Groundwater Plume Phase II Pre-Operational Ecological Sampling Plan* (AFCEE 1998d) were written, and all sampling and analyses were conducted, in accordance with the *Quality Program Plan* (QPP) (AFCEE 1998a). Summaries of field and analytical data from summer 1996, fall 1996, spring 1997, (Phase I) and fall 1997, spring 1998, and summer 1998 (Phase II) have been presented in other reports (AFCEE 1998g, 1998h, 1998i).

1.1 PURPOSE

The purpose of the Ecological Studies Program is to monitor the groundwater and the surface water ecosystems adjacent to and downgradient of each groundwater treatment system, and to assess the impacts of the treatment system so that actions can be taken to eliminate or minimize negative impacts to ecosystems. This report focuses on ecosystems associated with the FS-12 ETR system which consists of 25 extraction wells and 23 reinjection wells. This treatment system may change characteristics of the groundwater and surface water such as water levels, pH, temperature, dissolved oxygen (DO), and nutrients. These parameters are, in part, measures of the health of an ecosystem.

1.2 OBJECTIVES

The Ecological Studies Program assessed the potential for impacts from groundwater treatment system in two phases. Phase I was the period from the beginning of the investigation to several weeks before the ETR system began operating (usually one year). This pre-operational baseline was designed to characterize the potentially impacted (study) ecosystems and reference ecosystems. Phase II begins with the commencement of the ETR system. Phase II of the program was designed to detect and evaluate undesirable ecological impacts that could result from the extraction of contaminated water or the addition of treated water from treatment system operated to remediate groundwater plumes.

This assessment was made by comparing conditions observed at the potentially impacted sites during Phase II with conditions documented at the potentially impacted sites during the pre-operational characterization of Phase I, and with conditions at reference ecosystems not impacted by MMR or plume response actions.

Phase II data were evaluated to determine if any adjustments to the ETR system were necessary to prevent or limit adverse impacts on the potentially affected sites. Ecological criteria guidelines were used to identify maximum levels of change in

biological communities and in physicochemical parameters that, if exceeded, could require a response. The following sampling activities were conducted during Phase II monitoring to assess potential impacts:

- Treatment plant water intake and outflow,
- Groundwater downgradient of a treatment plant to evaluate plume containment,
- Groundwater from selected upgradient wells to assess background characteristics,
- Groundwater, surface water, and biological resources in ecosystems potentially impacted by a groundwater treatment system and their reference systems.

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2.0 BACKGROUND

The annual assessment of the FS-12 treatment system was performed at MMR in the upper western portion of Cape Cod, Massachusetts. It occupies approximately 22,000 acres (35 mi^2) within the towns of Bourne, Sandwich, Mashpee, and Falmouth in Barnstable County.

2.1 HISTORY OF THE MMR

Military use of portions of MMR began as early as 1911. Most of the activity, however, has been conducted since 1935 and has included operations by the U.S. Army, U.S. Coast Guard (USCG), U.S. Air Force (USAF), Massachusetts Army National Guard (ARNG), U.S. Air National Guard (ANG), and Veterans Administration (VA). The level of activity at MMR has varied over its operational history.

Maintenance and other activities conducted at MMR have resulted in a number of contaminants being released into the environment, particularly the groundwater. These contaminated groundwater areas, or plumes, radiate from contaminant source areas within the MMR into the surrounding communities. One of these groundwater plumes is the FS-12 plume located in the eastern portion of the MMR (Figure 2-1).

2.2 FS-12 PLUME CHARACTERIZATION

The source of the FS-12 plume was a break in an underground fuel pipeline that extends 7.5 miles from the Cape Cod Canal to the refueling area on the flightline. The area of the break was along Greenway Road, north of CS-10. The pipeline carried aviation gasoline (AVGAS) and jet petroleum-4 (JP-4), and the fuel leak was estimated at 70,000 gallons. Benzene and ethylene dibromide (EDB) were the primary fuel-related contaminants of concern in the FS-12 plume and have been detected at concentrations exceeding their maximum contaminant levels (MCLs) of 5 µg/L and 0.02 µg/L, respectively (Advanced Sciences 1995).

The FS-12 plume extends outside the boundary of the MMR, beneath the Village of Forestdale within the Town of Sandwich. It also underlies most of Camp Good News, a privately owned summer camp facility located along a portion of the eastern boundary of MMR. Ongoing investigations have provided additional information on the nature and extent of the plume as follows:

- As it migrates, the top of the FS-12 plume extends from the water table, approximately 68 ft mean sea level (msl), to 128 ft below the water table or 60 ft below msl. The plume is approximately 1,600 ft wide, 130 ft thick, and 4,700 ft long (AFCEE 1998g).
- In 1996, the maximum concentration of benzene and EDB detected in groundwater from wells at FS-12 was 2,700 and 890 μg/L, respectively (AFCEE 1998g).
- The secondary plume contaminants include toluene, ethyl benzene, xylenes, chloroform, cis-1,2-dichloroethane, 1,3,5-trimethylbenzene, n-propylbenzene, naphthalene, 2-methylnaphthalene, iron, manganese, zinc and bromide (AFCEE 1998g).
- The hydraulic conductivity of the aquifer is approximately 422 ft/day (OpTech 1996).

2.3 FS-12 ETR SYSTEM

The treatment plant for the FS-12 ETR system is located on the MMR north of Snake Pond. The treatment system consists of 25 extraction wells and 23 reinjection wells located northeast of Snake Pond (Figure 2-2). The extraction wells were installed at a depth of –61 to 24 ft msl and can pump about 10 to 60 gpm. The reinjection wells were installed at a depth of –61 to 24 ft msl and receive approximately 7 to 53 gallons per minute (gpm). Groundwater treatment includes greensand filtration and carbon filtration to remove contaminants and other organic compounds. Ultraviolet oxidation units are available to treat high concentrations of contaminants if necessary.

2.4 FS-12 PREVIOUS INVESTIGATIONS

The ecological investigation began in July 1996 and continues, with results presented in several reports.

Results of the Phase I Ecological Monitoring Program were presented in the *Final Ecological Studies 1997 Annual Report for FS-12, SD-5 and CS-10 Groundwater Plumes* (AFCEE 1998g). The following is a summary of the findings:

- Inflow in Snake Pond is in the northern portion of the pond, and outflow is in the southern portion. Most of the flux into and out of the pond occurs near the shoreline. The northern-most cove consists of low hydraulic conductivity sediments, and seepage into the cove area is very low. Modeling results indicate that the groundwater flux into Snake Pond is between approximately 63,000 ft^3/day and 96,000 ft^3/day and the residence time is between 1 and 1.3 years (AFCEE 1998g).
- Differences in physicochemical properties between surface water and groundwater were markedly different. Surface water showed a much greater range in temperature and pH than groundwater (AFCEE 1998g).
- Surface water sampling did not indicate plume contaminants impacting the downgradient ecosystems. Secondary contaminants, 1,2-dichloroethane and toluene, were detected in Snake Pond. Cis-1,2-Dichloroethane was detected at four locations in the fall 1996 sampling round with a maximum concentration of 4 µg/L. It was not detected in subsequent sampling rounds. Toluene was detected at 1.73 µg/L at location ECSNP07 in summer 1997, but was not detected at this location in spring 1997 (AFCEE 1998g).
- Eight species of plants and animals protected by the Massachusetts Endangered Species Act were sighted in the Snake Pond area during the study (AFCEE 1998g).
- Ecological criteria guidelines for Tier I parameters during the Phase I investigation between study areas and reference areas may not be practical for surface water during transition periods when the ponds are trending toward either winter or summer conditions or during periods of peak biological activity (AFCEE 1998g).
- Iron and manganese were identified as chemicals of potential concern (COPECs) in both surface water and sediment at Snake Pond (AFCEE 1998g).

The *Draft May 1998 Ecological Assessment Report on the Fuel Spill-12 and Storm Drain-5 North Treatment Systems* (AFCEE 1998i) compared Phase I results for temperature, DO, pH, and dissolved organic compounds (DOC) with sampling results from November 1997 and May 1998 (Phase II). There was no evidence of adverse impacts attributable to the start-up of the treatment plants. No surface water exceedences of the ecological criteria guidelines were found. Temperature did

exceed ecological criteria guidelines for groundwater because the downgradient groundwater was significantly cooler than the upgradient groundwater. There is no mechanism for the ETR system to cool groundwater and, therefore, the anomaly was declared unrelated to the ETR system (AFCEE 1998i).

The *Draft August 1998 Ecological Assessment Report on the Fuel Spill-12 and Storm Drain-5 North Treatment Systems* (AFCEE 1998h) did not show any exceedences of ecological criteria guidelines for pH, temperature, DO, and DOC for FS-12. (AFCEE 1998h). Results from chemical sampling were deferred until the annual report for 1998 (November).

Chemical sampling was conducted nine times, including baseline, under the Performance Monitoring Evaluation (PME) Program, and hydraulic monitoring was done 15 times including baseline. Reports were prepared for all data collected from September 18, 1997 (plant start-up) through December 31, 1998 (AFCEE 1998b, 1998e, 1998f, 1998j, 1999). The findings from these reports were as follows:

- The response of the aquifer to the stresses caused by the ETR system was nearly the same as the response predicted by computer simulation. Drawdown and mounding happened as expected (less than 0.5 ft) in the immediate vicinity of the extraction and reinjection wells.
- Chemical monitoring had detected some change in the plume location. The central portion of the plume, where EDB and benzene concentrations were highest, had migrated in the direction of groundwater flow towards the toe extraction fence.
- The toe extraction and reinjection fences appeared to be containing the contaminants. No breakthrough was detected, although some contaminants were detected that were downgradient of the system prior to start-up. A series of downgradient monitoring locations, known as the Phase II monitoring network, were installed to monitor for movement of this contamination. The downgradient contamination had not reached the wells.
- By October 31, 1998 the treatment plant had treated 430 million gallons of contaminated water and removed 83 pounds of EDB and 71 pounds of benzene from the groundwater.

2.5 REGIONAL HYDROGEOLOGY

A single groundwater flow system underlies Upper Cape Cod, defined as the area from the Cape Cod Canal to the communities of Barnstable and Hyannis. This sole-source aquifer, the Sagamore Lens, provides Upper Cape Cod's only potable water source. Infiltration of precipitation recharges the unconfined aquifer in the northern portion of MMR. Recharge is approximately 1.6 ft per year with seasonal variations producing annual water table fluctuations of 1 to 3 ft. Groundwater flow is radial from this recharge area (ANG 1992).

Large-scale flow within the aquifer is predominantly horizontal. Upward vertical hydraulic gradients near surface water bodies are common in glacial terrain such as the Mashpee Pitted Plain kettle ponds. These gradients are sufficient to cause groundwater flowing at shallow depth to discharge into Ashumet Pond, Johns Pond, and other surface water bodies (ANG 1992). Surface water features, such as drainage swales, ponds, marshes, streams, and rivers also influence groundwater flow, direction, and water table slope on a regional scale.

The ocean forms the lateral boundary of the Sagamore Lens on three sides with groundwater discharging into Nantucket Sound on the south, Buzzards Bay on the west, and Cape Cod Bay on the north. The Bass River in Yarmouth forms the eastern boundary of the aquifer.

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3.0 INVESTIGATION ACTIVITIES

Phase II ecological data were collected from select reinjection wells, from upgradient and downgradient groundwater, and from surface water, sediment, and biota at Snake, Peters, Weeks, and Triangle ponds. Physicochemical parameters measured included field parameters (pH, temperature, DO, specific conductivity, oxidation-reduction potential, turbidity), DOC, dissolved inorganic compounds (DIC), ammonia, nitrate, nitrite, orthophosphate, alkalinity, hardness, total suspended solids (TSS), total dissolved solids (TDS), total nitrogen, and total phosphorus. Chemical parameters measured include Environmental Protection Agency (EPA) Contract Laboratory Program (CLP) target compound list (TCL), volatile organic compounds (VOCs), CLP target analyte list (TAL) metals, and EDB. Biological parameters measured were phytoplankton, zooplankton, benthic macroinvertebrates, vegetation, and fauna. These data were used to determine whether the ecological resources were being impacted by the operation of the FS-12 treatment system using comparisons between potentially impacted sites and reference sites (Figure 3-1). All analytical methods used in the Ecological Studies Program are presented in Table 5-4 of the *Final Work Plan for the Ecological Assessment Associated with Groundwater Plumes and Remedial Activities* (AFCEE 1998c).

3.1 TREATMENT PLANT DIRECT IMPACT MONITORING

Select upgradient monitoring wells and reinjection wells (Table 3-1, Figure 3-2) were monitored monthly for physicochemical parameters to determine the potential impacts of the treatment system on these parameters.

3.2 HYDROLOGICAL DATA COLLECTION

Hydrological monitoring included surface water and groundwater levels. The effectiveness of the treatment system on contaminant removal was measured according to the PME plan for FS-12 (AFCEE 1998b). The PME plan includes groundwater sampling for plume extent monitoring, breakthrough monitoring, and

reinjection impact monitoring. Whenever possible, Phase II ecological sampling was conducted simultaneously with PME sampling.

3.2.1 Water Level Monitoring

Water levels were measured from monitoring wells, piezometers, in-pond staff gauges, and microwells to evaluate groundwater and surface water fluctuations.

- Weekly: staff gauges were measured from June through November 1998 (Table 3-2, Figures 3-3, 3-4, and 3-5).
- Quarterly: groundwater levels were taken from wells when sampled for physiochemical parameters (Table 3-3).
- Annually: a comprehensive synoptic water level survey was conducted in study area (Table 3-4, Figure 3-6).

Water levels were measured according to the technical procedure "Static Water Level and Total Depth Measurement" TECH-006 (AFCEE 1998a).

3.2.2 Groundwater Sampling

Groundwater was sampled from microwells, monitoring wells, and piezometers to monitor for changes in water quality. Groundwater samples were analyzed for EPA CLP TCL VOCs, CLP TAL metals, EDB, selected inorganic constituents (anions) and field parameters. Routine groundwater sampling included the following:

- *Monthly*: upgradient groundwater and select reinjection wells were sampled for physicochemical parameters (Table 3-1, Figures 3-2 and 3-7).
- *Quarterly*: chemical and physiochemical analysis were performed on groundwater sampled at select wells (Table 3-3, Figures 3-2 and 3-7).

Sampling was conducted using a low-flow method following Groundwater Purging and Sampling Procedure, Low-Flow and Standard Method, TECH-015 (AFCEE 1998a). Hydrologic data sampling location for the reference areas are presented in Figure 3-7.

3.3 SURFACE WATER DATA COLLECTION

Phase II surface water was sampled and analyzed for chemical and physicochemical parameters (Table 3-5, and Figures 3-3, 3-4, and 3-5). Surface water was sampled at Snake, Triangle, and Peters ponds. Snake Pond was used as the study pond and Triangle and Peters ponds were used as the reference areas for Snake Pond (Figure 3-1). Sample locations used for Phase II were the same as those used in the Phase I investigation (AFCEE 1997).

Specific conductivity, turbidity, oxidation reduction potential (ORP), temperature, DO, and pH were measured in the field every three feet through the entire water column at each sample location. Secchi disk depth was measured at each location. The following parameters were measured at off-site laboratories:

- TDS, TSS, alkalinity, TOC, DOC, DIC, ammonia, nitrate, nitrite, orthophosphate, total nitrogen, and total phosphorous were measured at one meter below the pond surface.
- CLP target compound list (TCL) VOCs, EDB, and CLP TAL total metals samples were collected from adjacent surface water and sediment when plume-related contaminants were detected in microwells. Adjacent surface water constitutes a surface water sample taken within 3 ft from the pond bottom near the affected microwell. Because no plume contaminants were detected in Snake Pond during the monitoring period, no adjacent surface water or sediments were collected from the 1998 sampling season.

3.4 BIOLOGICAL DATA COLLECTION

Field sampling and surveys were conducted at surface water ecosystems to document the status of biological resources (Table 3-6). The following ecological receptors were surveyed as part of the ecological characterization associated with the FS-12 plume: phytoplankton, zooplankton, benthic invertebrates, aquatic vegetation, shoreline vegetation, threatened and endangered species, and species of special concern.

3.4.1 Phytoplankton Sampling

Phytoplankton were sampled for species composition and enumeration from study and reference ponds at the same location as the surface water samples (Figures 3-8, 3-9, and 3-10). Phytoplankton data were used to help assess the trophic state of the ponds. The trophic state refers to the state of productivity of a pond. The phytoplankton are considered primary producers and the first trophic level of the pond. The number and variety of phytoplankton species are an indicator of the relative trophic state of a pond.

In 1997 phytoplankton samples were collected in triplicate from one depth, 3 feet, at each surface water sampling location in the ponds. However in 1998, the Ecological Studies Program determined it would be more useful to characterize the phytoplankton in the photic zone rather than from one depth. Different phytoplankton species have evolved to be able to adjust their buoyancy for utilizing different wavelengths of light for photosynthesis and for finding nutrients. The photic zone was defined as the depth in the pond extending to the one percent light level. This depth was approximated by two times the Secchi disk depth (Parsons et al. 1977). As such, the sampling protocol for phytoplankton was amended for use in 1998 as follows:

- Samples were collected from a depth of 3 feet below the surface of the pond for characterizing the upper portion of the photic zone.
- Samples were collected from a depth of approximately one half the distance from the surface of the pond to two times the Secchi disk depth (the one percent light level) for characterizing the middle portion of the photic zone.
- Samples were collected from a depth of approximately two times the Secchi disk depth for characterizing the lower portion of the photic zone.

Phytoplankton samples were collected in the late spring through late summer of 1998 (May, June, August, and September) according to "Phytoplankton Sampling," TECH-057 (AFCEE 1998a) and identified to the lowest practical taxonomic level.

3.4.2 Zooplankton Sampling

Zooplankton samples were collected for species composition and enumeration from study and reference ponds at the same location as the surface water samples (Figure 3-8, 3-9, and 3-10). Zooplankton data were used to help assess the trophic state of the ponds. Zooplankton represent the second trophic level of the pond. The zooplankton feed on phytoplankton. The amount and variety of zooplankton in a pond are indicators of the trophic state of the pond.

In 1997 zooplankton samples were collected in triplicate from one depth (i.e., 3 feet) at each surface water sampling location in the ponds. Because of zooplankton mobility, the Ecological Studies Program determined in 1998 it would be more useful to characterize the zooplankton throughout the water column of the ponds rather than from one depth. Zooplankton samples were collected in late spring through late summer of 1998 (May, June, August, and September). Zooplankton samples were collected in accordance with "Zooplankton Sampling," TECH-058 (AFCEE 1998a) and identified to the lowest practical taxonomic level.

3.4.3 Benthic Macroinvertebrate Sampling

Benthic macroinvertebrate samples were collected for species composition and enumeration from ten locations in study and reference ponds (Figures 3-8, 3-9, and 3-10). Benthic macroinvertebrate data are a component used to assess the trophic state of the ponds. Benthic macroinvertebrates, like zooplankton, occupy the secondary or tertiary trophic levels by feeding on phytoplankton and zooplankton in the ponds. The number and variety of benthic macroinvertebrates in a pond are an indicator of the trophic state, or the state of productivity for the pond.

In 1997 benthic macroinvertebrate samples were collected in triplicate from each surface water sampling location in the ponds. Because of heterogeneity of these communities, in 1998 the Ecological Studies Program determined it would be more useful to characterize benthic macroinvertebrate communities based on sediment

substrate (areas where the most common substrate was found in the ponds) and from sediment depths above the hypolimnion (areas where organisms are not stressed due to their physical environment). Additionally, more community information could be obtained from additional sample locations rather than collecting three samples from each surface water sampling location. Benthic macroinvertebrate samples were collected in June and September 1998. Benthic macroinvertebrate samples were collected in accordance with "Benthic Macroinvertebrate Sampling," TECH-059 (AFCEE 1998a) and identified to the lowest practical taxonomic level.

3.4.4 Vegetation Surveys

Vegetation was surveyed during the 1998 field season at the study and reference areas. Vegetation sample plots established during the 1997 field season were re-inspected in accordance with Survey Techniques for Aquatic Shoreline and Wetland Vegetation Communities, Tech-032 (AFCEE 1998a); the plant communities were then characterized. The vegetative sampling surveys performed as part of the Ecological Studies Program over the past three years have established a reference database for vegetative sample plots located at the study areas and the designated reference areas.

3.4.5 Threatened and Endangered Species and Species of Special Concern

Threatened and endangered species surveys were performed in accordance with the technical procedure MMR Tech-033, Procedures for Surveying Rare Species, to investigate and document the presence of state-listed rare plants and animals at the study and reference areas. Bird surveys were conducted in accordance with Bird Surveying Protocols, Tech-050 (AFCEE 1998a). Qualified botanists with local experience recorded the presence of rare species, threatened and endangered species, and species of special concern. Field information recorded included the location of the population and its size, and evidence of expansion or decline in the population. Rare plant and animal element occurrence forms were completed and copies

submitted to the Natural Heritage and Endangered Species Program, Westborough, MA.

3.5 QUANTITATIVE ANALYSES

Statistical analyses were performed to assess the data collected by the Ecological Studies Program. A variety of quantitative analyses on Tier I and Tier II parameters was conducted to determine whether the ETR system was affecting the ecosystems downgradient of it. A two-tiered approach was used to assess the short- and long-term effects of the treatment system. Ecological criteria guidelines were developed to provide a benchmark for comparison of Tier I and Tier II parameters.

3.5.1 Ecological Criteria Guidelines

Ecological criteria guideline values were developed in conjunction with the EPA, the DEP, and the TRET (Table 3-7). Ecological criteria guidelines were used to identify levels of change in biological communities and physicochemical parameters that, if exceeded, may require a response.

The ecological criteria guideline values were used to identify unacceptable levels of change in an ecosystem by comparing proportion changes between study ecosystems and reference ecosystems.

A two-tiered approach was developed to provide a framework for assessing the potential ecological impacts. Tier I elements are those parameters that provide an acute assessment of changes in the ecosystem that may be related to a groundwater treatment system. Tier I parameters are field measurements of water level, pH, temperature, and DO; DOC, also a Tier 1 parameter, is determined by laboratory analysis. Tier II elements are defined as those measurements that represent chronic indicators of ecosystem health. Tier II elements include measurements such as trophic state, aquatic biological resources, and distribution of shoreline vegetation.

Tier I constituents can be used to identify direct and immediate impacts on the ecosystem that may be related to the operation of a groundwater treatment system. If a Tier I constituent had exceeded the ecological criteria guideline value, then a determination was made if the exceedence was treatment system-related.

Tier II constituents are those parameters which may reflect long term effects of the ETR system on the potentially impacted or study ecosystems. If a Tier II constituent had exceeded the ecological criteria guideline value, then a determination was made if the exceedence was treatment system-related, based on weight-of-evidence analysis (EPA 1996, Menzie et al. 1996, DEP 1996). The weight-of-evidence approach is discussed in the *Final Work Plan for the Ecological Assessment Associated with Groundwater Plumes and Remedial Activities* (AFCEE 1998c). When a Tier II parameter exceeds a guideline, it is difficult to attribute this to a treatment system if the evidence shows that there are no initial exceedences in Tier I parameters resulting from the operation of the groundwater treatment system.

3.5.2 Statistical Analyses

A variety of statistical analyses were implemented to characterize the ecosystems around the FS-12 ETR system. Analysis of variance procedures were used to determine the amount that factors, such as season or pond depth, contributed to the population variability. A series of two sample tests was used to determine the statistical significance of Tier I parameters analyzed for ecological criteria guidelines. Univariate analyses were performed on water levels to determine whether ecological criteria guidelines had been exceeded. Univariate analyses were also performed on Tier II parameters to characterize their distributions. Decisions on the effectiveness of the ETR system were dependent upon the assessment of ecological criteria guidelines and not these statistical tests.

3.5.2.1 Analysis of Variance

A one-way analysis of variance procedure was performed on groundwater and surface water data from the ecological monitoring of the ETR system. The one-way analysis of variance procedure is used to assess the differences between a categorical variable (a nominal variable such as *yes* or *no*) and one response variable (an interval or ratio variable such as c*oncentration*). The response variables for this investigation were the Tier I parameters of temperature, pH, DO, and DOC. All analyses were tested for significance at the 95 percent confidence level (α=0.05). This procedure was used to determine the amount of variability exhibited by the response variable attributable to each group (categorical variable) and to assess the variability between groups (Ott 1988).

The one-way analysis of variance procedure assumes that the populations analyzed have normal distributions and equal variances. In these experiments, it was assumed that all populations exhibited equal variances. Normality was assumed based on the Central Limit Theorem which states that, "if random samples of n measurements are repeatedly drawn from a population with a finite mean μ and a standard deviation σ, then when n is large, the relative frequency histogram for the sample means (calculated from the repeated samples) will be approximately normal (bell-shaped with mean μ and standard deviation $\sigma/\sqrt{n}$. (Note: the approximation becomes more precise as n increases)." (Ott 1988:109).

The Fisher's Least Significant Difference (LSD) multiple comparison test was used to determine differences between groups. The Fisher's LSD is a very conservative test in which small differences between groups are given more power. There is a high probability of a Type I error (declaring a group different when it is actually the same) with this test, although the work plan indicates that it is more important to control for a Type II error (declaring a group similar when it is actually different) than a Type I error (AFCEE 1998c). The Fisher's LSD test screens the data prior to the ecological criteria guideline assessment to alert researchers to the need for an investigation of differences that exist in the population (Saville 1990).

The groundwater data for the one-way analysis of variance were partitioned into several groups for analysis. These groupings were as follows:

- Relative Location: the location of the groundwater sample with respect to the ETR system.
  - Upgradient groundwater - included upgradient and in-plume wells
  - Downgradient groundwater - included treated water from the reinjection wells and downgradient monitoring wells at Snake Pond
  - Reference groundwater - monitoring wells from Triangle and Peters ponds

- Phase: time when the groundwater sample was collected before or after treatment system start-up.
  - Phase I - samples collected prior to ETR system start-up (September 18, 1997)
  - Phase II - samples collected after ETR system start-up (September 18, 1997)

- Season: time of year the sample was collected.
  - Winter - samples collected between December 21 and March 20
  - Spring - samples collected between March 21 and June 20
  - Summer - samples collected between June 21 and September 20
  - Fall - samples collected between September 21 and December 20

The surface water data were analyzed in a similar manner. The surface water data were divided into the following categories:

- Class: whether the samples were collected from a potentially impacted area (study pond) or an unaffected area (reference pond).
  - Study pond - surface water samples collected from Snake Pond
  - Reference ponds - surface water samples collected from Triangle and Peters ponds

- Limnion: for purposes of the data review, the surface water body was classified as one of two layers, either epilimnion or hypolimnion. These layers are separated by the thermocline, beginning at the depth where there is at least a 1° C change in temperature corresponding to a 3-foot change in depth. Those depths corresponding to the thermocline were assigned to the epilimnion, and those below this depth were assigned to the hypolimnion. The thermocline was further

defined as the shallowest depth from among multiple sample locations within a surface water body at which this temperature decline occurred.

- Epilimnion - surface water samples collected above or in the thermocline of a stratified pond, a pond that has significantly warmer waters at the surface and cooler waters at the pond bottom
- Hypolimnion - surface water samples collected below the thermocline of a stratified pond

The one-way analysis of variance procedure was used for testing the groundwater and surface water for differences within groups and determining variability between groups. These tests were performed in the following manner:

- Multiple comparison test - used to determine which categories within a group are significantly different from the others. For example, the test may conclude for the season factor that fall and winter groups are significantly different from summer, but not significantly different from spring.
- Between group comparisons - the one-way analysis of variance procedure tests the difference of the between groups sum of squares (model) against the within groups sum of squares (error). The between groups sum of squares is a measure of the amount of variability explained by the categorical variables. By analyzing the between group sum of squares (variation in the data population attributed to a factor) to the total sum of squares (total variation in the population), a percentage can be calculated to determine how much relative variability is defined by that factor. The factors can then be compared to determine which factors contribute more to the total explainable variability. In this manner, one can determine, for example, if seasonal variation of temperature in the surface water contributes more to the total variability than the location from which the samples were collected.

3.5.2.2 Two-Sample Tests

The assessment of ecological criteria guidelines was tested using two-sample tests for significance. These tests were used to assess whether a statistical difference was evident regardless of the comparisons for ecological criteria guidelines. Tests for significance were defined at the 95 percent confidence limit (α=0.05). Tests of the null hypothesis (Ho) were performed for each two sample test. The null hypothesis states that there is no significant difference between the two populations that are compared. A rejection of the null hypothesis means that one is confident that the two

data sets were drawn from different populations. An acceptance of the null hypothesis means that one is 95 percent confident that the two data sets were drawn from the same population.

Two-sample tests were used to determine the statistical significance of ecological criteria guidelines. These tests involved the comparison of two populations with a student's t-test, which assumes that the two populations were normally distributed and had equal variances. It was assumed, according the Central Limit Theorem, that populations of 30 observations or more were normally distributed. The Omnibus Normality Test (D'Agostino, et al. 1990) was used to test the normality of distributions where there were less than 30 observations. The Modified Levene Equal Variance Test (Conover 1981) was used to test for equal variance. For populations with unequal variances, an unequal variance t-test was incorporated. For populations with non-normal distributions, non-parametric tests were used to test for differences in medians or distributions (Hintze 1997). It should be noted that non-parametric tests usually have lower power than parametric tests.

- Equal Variance t-Test (normal distributions with equal variance): tests for difference between the means of two populations.
- Aspin-Welch Unequal Variance t-Test (normal distributions with unequal variance): tests for the difference in means of two populations.
- Wilcoxon Rank-Sum Test (non-normal distributions with equal variances): non-parametric test for the difference in medians of two populations.
- Kolmogorov-Smirnov Test (non-normal distributions with unequal variances): tests for the difference in the distribution of two populations, not necessarily the mean or median (Hintze 1997).

Groundwater Tier I data were subjected to the two-sample tests for comparison Phase I downgradient groundwater to reference groundwater and Phase II downgradient groundwater to reference groundwater.

- Downgradient groundwater - groundwater from selected wells downgradient of the ETR system that included the microwells in Snake Pond and excluded the reinjection wells.

- Reference groundwater - groundwater from microwells in Peters and Triangle ponds.

Surface water Tier I data were treated similarly. Study surface water was compared to reference groundwater. Two tests were performed on Phase I surface water data and Phase II surface water data.

- Study surface water - surface water samples from Snake Pond
- Reference surface water - surface water samples from Peters and Triangle ponds.

The results of the two-sample tests were compared to ecological criteria guidelines calculated for groundwater and surface water. Because there was a high probability that populations that were significantly different might not exceed the ecological criteria guidelines, the two-sample tests were applied as a conservative approach to examine the differences in the two populations.

3.5.2.3 95 Percent Confidence Levels

The assessment of the ecological criteria guidelines vs. pond surface water levels and groundwater levels was based on the 95 percent confidence interval around the mean water levels. The mean and 95 percent confidence interval of the Phase I and II water level measurements from one upgradient well and one downgradient well were calculated. Similarly, the mean and 95 percent confidence interval of the Phase I and II water level measurements from each of four ponds—Snake, Peters, Triangle, and Weeks—were calculated. The confidence intervals for each of the two wells and four ponds were then compared to the ecological criteria guidelines of ± 0.5 feet. Weeks Pond was only studied for water levels.

3.5.2.4 Descriptive Statistics

Many of the parameters measured for the assessment of the FS-12 treatment system on ecosystems were not incorporated into the trophic state indices or Tier I determination of ecological criteria guidelines. These data were the physicochemical

parameters of ORP, turbidity, specific conductance, TDS, TSS, and alkalinity. The mean, standard deviation, and 95 percent confidence limits for these data were determined. Summary tables were prepared to display these analyses of physicochemcial parameters not defined as Tier I parameters. Where appropriate, groundwater was divided into upgradient, downgradient, and reference groundwater for Phase I and Phase II. Surface water was divided into study surface water (Snake Pond) and reference surface water (Peters and Triangle ponds) and Phase I/II data.

3.5.3 Richness, Evenness, and Diversity Indices

Three richness, one evenness, and two diversity indices were calculated for the biological data (phytoplankton, zooplankton, and benthic macroinvertebrates). The richness indices are a measure of the number of taxa in a community. The three indices used for this report include Gleason's Index (range 0 to infinity), Margealef's Index (range 0 to infinity), and Menhinick's Index (range 1 to infinity). These indices show an increase as the number of species (richness) increases (Slater 1986, Ludwig and Reynolds 1988).

Gleason's Index = $\dfrac{\sum a}{\ln \sum b}$

Margealef's Index = $\dfrac{a}{\ln \sum b}$

Menhinick's Index = $\dfrac{a}{\sqrt{\sum b}}$

a = number of lowest taxonomic groups identified
b = number of individuals identified

The evenness index is a measure of how the individuals are distributed among the various taxa. The evenness index ranges from 0 to infinity and increases as the individuals become more uniformly distributed.

$$\text{Evenness Index} = \frac{\text{Shannon's Index}}{\sum a}$$

a = number of lowest taxonomic groups identified

The diversity indices combine the measure of richness and evenness. The Simpson's Index ranges from 0 to 1; as the value of the index approaches 1, the diversity of the community sample is low. Shannon's Index ranges from 0 to infinity; the greater the value of the index, the greater the diversity. Shannon's Index attains a value of maximum diversity when the sample population is evenly distributed among the species (Slater 1986, Ludwig and Reynolds 1988).

$$\text{Simpson's Index} = \frac{\sum c(c-1)}{\sum b(\sum b - 1)}$$

$$\text{Shannon's Index} = \sum ABS\left[\left(c / \sum b\right) \times \ln\left(c / \sum b\right)\right]$$

a = number of lowest taxonomic groups identified
b = number of individuals identified
c = number of individuals identified in each taxonomic group

It should be noted that diversity indices do not compare specific taxa within or between the ponds; however, the indices are proportional to community sizes and differences in the total number of taxa found within and between the ponds.

3.6 DATA ADJUSTMENTS AND DEVIATIONS FROM THE WORKPLAN

There was no sampling at Camp Good News for reinjection wells (90RIW0006, 90RIW0014, and 90RIW0028) in summer 1998 (June, July, and August). AFCEE did not have access to those wells when the camp was in session that summer.

There were no ecological monitoring samples collected between November 1997 and May 1998 for contractual reasons. This deviation may have led to an under-representation of data for the winter and spring months. This deviation could have affected surface water measurements, particularly temperature dependent parameters such as DO. Samples collected for the PME program were collected during this time period. All PME samples that were collected from designated ecological monitoring program wells were included in the analysis. The PME program collected samples that were analyzed for VOCs, EDB, and TAL metals.

The final field parameter database was a combination of the following data points:

- A query of the project (field or YSI) electronic database for all data collected from 1996 through December 31, 1998.
- A review of the data created for the May and August 1998 ecological assessment reports (AFCEE 1998i, 1998h).
- A review of logbooks that included data not listed in the electronic database or May and August, 1998 ecological assessment reports.
- The DOC database was developed exclusively from a query of the electronic database.

Based on pond stratification, data were classified as either hypolimnion or epilimnion. The epilimnion was the only data used for two sample tests of surface water in the ponds for Tier I parameters. Both epilimnion and hypolimnion were used for the analysis of variance of the Tier I parameters and descriptive statistics of the remaining physicochemical parameters.

Surface water measurements from near the pond bottoms were adjusted to account for the increased turbidity caused by the bouncing of the instrument off the pond bottom.

YSI values were recorded at 3 ft intervals through the water column at a location within a pond. In most cases, the pond bottom, the final reading for a location, was indicated by a turbidity reading that exceeded 10 nephelometric turbidity units (ntus). This reading indicated that the sediment at the pond bottom had been disturbed, and the bottom had been reached. This was verified by a comparison of the depth at which the high turbidity reading was obtained and knowledge of the approximate pond morphology. Because the sample at the bottom contained sediment, it was determined to be not representative of the water properties at that depth. These measurements were evaluated for deletion from the database by the following procedure:

The YSI values associated with the final reading were, in most cases, inconsistent with the other values at shallower depths for a location. If the turbidity measurement exceeded 10 ntu, and was at the final depth for that location, it was deleted from the database. The remaining parameters (ORP, DO, specific conductivity, pH, and temperature) at that final depth were compared to the readings of the previous depth and the following tolerances:

- ORP — ± 1 mV
- DO — ± 0.1 mg/L
- specific conductivity — ± 1 μS/cm
- pH — ± 1 pH unit
- temperature — $\pm 0.1°$ C

If any of these tolerances were exceeded, all data corresponding to the final depth were deleted. If none were exceeded, only turbidity was deleted.

Tier I and physicochemical parameters were not reported if an "R" qualifier was attached as a result of data validation. For those analytes that were reported as non-detect (ND), a value of one-half the detection limit was used for the statistical analyses.

All negative turbidity readings were assigned a value of zero (0).

All groundwater and surface water samples that were collected under the Ecological Studies Program were included in the analyses of the Tier I parameters and other physicochemical data.

Chemical data were screened for VOCs, EDB, and metals using Drinking Water Standards for groundwater (DEP 1997) and Ecotox Thresholds for surface water and sediment (EPA 1995). All groundwater samples collected under the Ecological Monitoring Program for FS-12 (Tables 3-1 and 3-3) were screened for chemical and physicochemical parameters. This included the chemical analyses conducted by the PME Program as well and the Ecological Monitoring Program for FS-12.

4.0 RESULTS

4.1 HYDROGEOLOGY

4.1.1 Synoptic Water Levels

The annual synoptic water level study was conducted in May 1998 (Figure 4-1). The synoptic water level analysis showed that between May 1997 and May 1998 water levels rose approximately 1 foot in both Snake Pond and the surrounding water table. The surface water elevation of Snake Pond rose from 70.42 to 71.52 ft. The rise in the groundwater table elevation was observed in monitoring locations situated upgradient of the FS-12 ETR system as well as locations downgradient of the system. It appears that this increase in surface water and water table elevations may be attributable to a period of heavy rainfall between January and May 1998. In that period, precipitation of approximately 27 inches was recorded for the greater MMR area. Based on precipitation totals recorded by the Otis Air National Guard Base Operations, the average precipitation amount for the months of January through May over the last 12 years (1986 through 1997) is approximately 21 inches. This higher than normal precipitation is augmented by an above-average precipitation total for 1997 (AFCEE 1998i).

The results of the May 1998 synoptic survey revealed areas of localized mounding in two areas of Snake Pond (Figure 4-1). Approximately 0.3 ft of mounding was recorded in the area of multipoint well 90MP0060 and reinjection well 90RIW0010. Approximately 0.25 to 0.5 ft of mounding was recorded in the areas of monitoring wells 90MW0058 and 90MW0085 and reinjection wells 90RIW0013 and 90RIW0014 (AFCEE 1998i).

The May 1998 synoptic survey results also indicated a localized area of groundwater drawdown (0.25 to 0.50 ft) in the south-center portion of the FS-12 plume. This area of drawdown may be attributed to the operation of the central extraction fence because the extraction fence pumps groundwater from the well to the ETR (Figure 4-1) (AFCEE 1998i).

4.1.2 Surface Water Levels

Surface water levels were measured at Snake, Weeks, Triangle, and Peters ponds as part of the Tier I data set. Water levels for all four ponds have been measured since 1996 by one staff gauge in each pond.

The general trend for the surface water levels of the four ponds is related to the amount of precipitation received over the course of the Phase II study. Figure 4-2 shows the relative surface water levels of the three ponds in relation to the measured precipitation from July 1997 to December 1998. The figure shows that the surface water levels of the three ponds co-vary with surface water levels lows occurring around November 1997 and reaching their highest levels around October 1998. Any influence from the treatment system is not evident because all three ponds show similar fluctuations through time.

An examination of the ecological criteria guidelines comparing Snake and Weeks ponds to Peters and Triangle ponds (Table 4-1) shows that no guidelines were exceeded. Table 4-1 shows that the greatest fluctuation in water levels occurred at Weeks Pond with a 95 percent confidence level on the mean calculated at ±0.28 ft. Treated water had not reached Weeks Pond by December 1998. Therefore, the greatest fluctuations in a pond are attributed to naturally occurring phenomena. Figure 4-3 shows the relative difference between the mean water levels and their 95 percent confidence levels. All ponds are well within the ecological criteria guideline of ± 0.5 ft. Furthermore, as indicated in previous reports, (AFCEE 1998h) the groundwater from discharge from the FS-12 ETR was expected to reach Snake Pond by March 1998 and Weeks Pond by April 2007. However, the dates of arrival are only estimates and cannot be confirmed by the environmental assessment. Peters and Triangle ponds are not within the area of the plume and are not affected by treated groundwater.

4.1.3 Groundwater Levels

Changes in groundwater levels were measured at two monitoring wells: one upgradient (90MW0020) and one downgradient (90MW0058) of the FS-12 ETR system. It is believed that this comparison should well-characterize the changes in groundwater levels in relation to the ETR. Table 4-1 shows the greatest fluctuation in groundwater levels occurred at 90MW0020 with a mean difference of ±0.61 ft. This value exceeds the ecological criteria guideline value of ±0.5 ft established for surface water. There was no ecological criteria guideline value for groundwater fluctuations (Table 3-7) but surface water guidelines for ponds were applied to groundwater in this investigation. The downgradient well showed far less variability with a mean difference of ±0.16 ft, well within the guidelines for surface water. It is notable that the greatest fluctuations occurred up- and cross-gradient of the ETR system and is most likely a fluctuation due to natural phenomena because the upgradient well is outside the localized area of drawdown from the extraction fence and the ETR was monitored to prevent significant water level fluctuations downgradient of the treatment system. Figure 4-5 shows the relationship between mean differences of the upgradient and downgradient groundwater.

4.2 GROUNDWATER CHEMISTRY

Tier I parameters in groundwater were initially analyzed by an analysis of variance procedure to determine the factors that most contributed to the variability of the data sets. The data were then subjected to two sample tests comparing downgradient and reference groundwater for Phase I and Phase II studies. These means were compared to ecological criteria guidelines to determine if any exceedences had occurred. Summary statistics on physicochemical parameters and maximum concentration limit (MCL) exceedences for chemical parameters were also determined.

4.2.1 Analysis of Variance

The analysis of variance procedure was performed as an assessment of Tier I parameters. The Tier I parameters included temperature, pH, DO, and DOC. The

data were categorized by the following independent factors: relative location (upgradient, downgradient, reference), season (winter, spring, summer, fall), and phase (collected during Phase I or Phase II sampling events).

4.2.1.1 Temperature

The greatest contributor to the variance of the temperature data set was the season factor which represented 27.2 percent of the variability (Table 4-2, Figure 4-6). The integrity of the data set was confirmed by the measurements of the lower groundwater temperatures during the winter season (10.0° C) and the warmer temperatures occurring in the summer season (13.7° C). The relative location was the second greatest contributor to the variability in temperature, explaining 10.1 percent of the total variation. It is interesting to note that the coolest groundwater temperatures were found in the groundwater downgradient of the ETR and the warmest in the reference groundwater. Because the ETR system has no process to cool groundwater prior to reinjection, this confirms that the ETR system has had little effect on the groundwater temperature. In addition, the phase factor only contributes 0.16 percent of the total variability in the temperature data set; the Fisher's LSD indicates that there is no significant difference between the Phases I and II mean temperatures.

4.2.1.2 pH

The analysis of variance performed on the pH data indicate that the relative location of the wells explained 42.4 percent of the total variance that was exhibited (Table 4-2, Figure 4-6). The groundwater from downgradient wells had a higher mean pH than groundwater from wells upgradient or from reference areas. This is not necessarily due to the ETR, as the Fisher's LSD indicates that there is no significant difference between the means of Phase I and II pH, and the Phase comparison explains only 1.00 percent of the variability.

4.2.1.3 DO

The results of the DO study were similar to the results of the pH study; of the variability explained by the model, the primary contributor was relative location at 14.98 percent (Table 4-2, Figure 4-6). The mean DO value of the downgradient wells was greater than that of the upgradient or reference wells. This may be explained by the lower DO concentrations in groundwater located in the plume due to biological activity compared to groundwater downgradient and in the reference areas where there is more dissolved oxygen. The contribution from the phase factor was virtually zero, with no significant difference in DO between Phases I and II.

4.2.1.4 DOC

The three components of the model explained less than 20 percent of the variability exhibited by DOC (Table 4-2, Figure 4-6). As with the other components, relative location was the greatest contributor to this variability at 9.92 percent. There was a significant difference between upgradient and downgradient groundwater due to the higher concentrations of DOC in the upgradient samples. The phase component explained 3.75 percent of the variability, and Fisher's LSD indicated that the means were significantly different with the Phase II mean higher.

4.2.2 Ecological Criteria Guideline Evaluation: Tier I Parameters

A series of two-sample tests was conducted comparing downgradient groundwater with reference groundwater. These tests were conducted using the Tier I parameters of temperature, pH, DO, and DOC. The data were first divided into Phase I and Phase II components, then analyzed as downgradient vs. reference. The results of these tests are presented in Table 4-3 and Figures 4-7 and 4-8.

4.2.2.1 Phase I Evaluation

The Phase I evaluation of groundwater included downgradient and reference groundwater samples collected prior to the start-up of the FS-12 ETR system. The

resultant analyses are biased by the low number (2) of reference groundwater samples collected prior to the startup of the treatment system. Therefore, significant results may be biased because of a lack of adequate sample size.

Two-Sample Test Results. The Phase I evaluation of Tier I parameters in groundwater shows that none of the parameters showed a significant difference between downgradient and reference groundwater. Due to a low sample size, three of the tests for difference between two groups were non-parametric tests (Table 4-3).

Ecological Criteria Guideline Results. The Phase I results show that three of the Tier I parameters exceeded the ecological criteria guidelines because (1) DO in the downgradient groundwater, (2) temperature of the reference groundwater, and (3) DOC in the downgradient groundwater (Table 4-3). These exceedences are not attributable to the FS-12 ETR system, because they are representative of data that were collected during Phase I. These exceedences ranged from 23.53 percent to 49.58 percent and are from natural variations in the data set (Figures 4-7 and 4-8).

4.2.2.2 Phase II Evaluation

There were more observations in the Phase II groundwater data than in the Phase I because Phase II reference groundwater data set had 14 observations and Phase I had only two. While more statistically significant, the number of observations was still too few to avoid non-parametric tests of significance. Results of the Phase II evaluation for groundwater are located in Table 4-3 and Figures 4-7 and 4-8.

Two Sample Test Results. The results of the two-sample tests for Phase II groundwater indicated that there was a significant difference between the downgradient and reference groundwater for three of the Tier I parameters. The mean temperature was significantly higher in the reference groundwater (13.89 °C) than in the downgradient groundwater (12.30 °C). Because the ETR system has no way of cooling groundwater prior to reinjection, it is believed this cannot be attributed to the ETR system. As in the Phase I results, the mean pH and DO were

higher in the downgradient groundwater. The pH of effluent from the ETR can be higher because of the anion exchange in the carbon filters that raises the pH of the water. The DO may be higher because of oxygen mixed in the process prior to reinjection. Most importantly, these results were not considered negative impacts to the downgradient groundwater (Table 4-3).

Ecological Criteria Guideline Results. The ecological criteria guidelines were exceeded only by DOC, with a means difference of 60.5 percent. The mean DOC of the downgradient groundwater was lower than that of the upgradient (0.5 mg/L, 0.8 mg/L). This was considered not to be a negative impact because the ETR system removes DOC from the groundwater prior to reinjection into the groundwater table. The removal of DOC is a desired effect and demonstrates that the ETR is performing adequately. However, according to the analysis of variance results (Table 4-2), only 3.75 percent of the variation in the DOC data set could be attributed to the operation of the ETR system. Therefore, the ETR system may have had minimal effect on the DOC concentrations in downgradient groundwater. All other Phase II parameters were well within the 20 percent ecological criteria guidelines (Table 4-3, Figures 4-7 and 4-8).

4.2.3 Physicochemical Parameters

Summary statistics for several field and physicochemical parameters in groundwater are presented in Table 4-4. These parameters include ORP, specific conductance, turbidity, TSS, TDS, total organic carbon (TOC), alkalinity, and dissolved inorganic carbon (DIC).

4.2.4 Chemical Parameters

Groundwater samples collected for 1998 were screened against drinking water standards (DEP 1997) for chemical and physicochemical parameters (Appendix H-1). A primary concern is an exceedence of EDB in Snake Pond microwell ECMWSNP02D of 0.029 µg/L from a sample collected in November. This

exceedence may indicate that some plume contaminants were not captured by the FS-12 ETR and were transported into the downgradient groundwater. The microwells in Snake Pond exhibited several exceedences for total metals. Total iron drinking water limits (300 µg/L) were exceeded for groundwater samples collected at ECMWSNP02D (1,360 µg/L—May 1998), ECMWSNP02S (7,850 µg/L—August 1998), ECMWSNP03D (1,950 µg/L—August 1998), and ECMWSNP03S (6340 µg/L—November 1998). Total nickel concentrations exceeded drinking water standards (100 µg/L) at Snake Pond microwell ECMWSNP02S (459 µg/L—August 1998). There was an exceedence of thallium drinking water standards (2 µg/L) at downgradient monitoring well 90MW0085B (3.2 µg/L—February 1998). The in-plume, upgradient groundwater monitoring well 90MW0020 showed drinking water exceedences of EDB (190 µg/L—January 1998), benzene (1,500 µg/L—January 1998), iron (1,270 µg/L—September 1998), and manganese (114 µg/L—September 1998).

4.3 SURFACE WATER CHEMISTRY

Surface water for the FS-12 investigation was focused on one study area, Snake Pond, and two reference areas, Triangle and Peters ponds. An analysis of variance procedure was performed on the surface water data to understand the variability of the Tier I parameters for pH, DO, temperature, and DOC. The variability was assessed for four factors as follows: class (study, reference), season (winter, spring, summer, fall), phase (Phase I, Phase II), and limnion (epilimnion, hypolimnion). These factors were analyzed to determine the amount of variability each factor contributed to the data set. The surface water was subjected to a series of two-sample tests for comparing study to reference ponds for Phase I and Phase II data. The means were used to assess the ecological criteria guideline exceedences for the Tier I parameters of pH, temperature, DO, and DOC. Physicochemical data from the ponds are presented in a statistical summary table (Table 4-4), and chemical data are discussed when ecological benchmark thresholds were exceeded (Appendix H-2).

4.3.1 Analysis of Variance

The analysis of variance of surface water at FS-12 demonstrated that the season factor was the single most significant contributor to the variability of the surface water data.

4.3.1.1 Temperature

The temperature data for surface water shows a strong influence by the season factor (Table 4-5 and Figure 4-9). The season factor contributed 46.0 percent of the total variability in the data set. The means show that there were higher surface water temperatures in the summer than in either the fall or spring. The limnion factor (depth) was the second most important factor contributing 3.58 percent of the total variability with higher temperatures in the epilimnion. The phase factor contributed 2.70 percent and the class factor contributed 1.41 percent of the variability observed in surface water temperatures. The Phase II surface water was cooler that that of Phase I, and the surface water of Snake Pond was cooler than the reference surface water, but the variability in the temperatures of the ponds is not attributed to the ETR system.

4.3.1.2 pH

The analysis of variance model for pH in surface can account for only 19.4 percent of the total variability in the data set (Table 4-5, Figure 4-9). The most important factor in the analysis was class with a contribution of 13.5 percent. The study pond surface water showed a statistically significant lower pH (6.60) than the reference pond surface water (6.93). The season factor was the next important factor explaining 5.08 percent of the variability. Spring pHs were somewhat higher than those in the summer or fall. There was a significant difference in the phase factor with Phase I exhibiting lower pHs than Phase II, but the phase factor explains only 0.73 percent of the total variation. The limnion factor showed no effect on the surface water pH.

4.3.1.3 DO

The single most important factor for explaining the variability of DO in surface water was the season factor (Table 4-5, Figure 4-9). The season factor accounted for 21.9 percent of the variability in the data set. The lowest mean DO was observed during the summer season when oxygen solubility was low and biological demand was high. The highest DO was observed in the spring when the waters were still cool from the winter season and oxygen solubility was high. The limnion was the second most important factor accounting for 4.83 percent of the total variability. Higher DO values were observed in the epilimnion. The class and phase factors contributed little to the total variability (0.18 percent and 0.01 percent, respectively). The Fishers LSD results show that there were no significant differences between the study and reference DO values, and between Phase I and Phase II. This suggests that the ETR system has had no effect on the DO in surface water of the downgradient ecosystems.

4.3.1.4 DOC

The analysis of variance model explained 5.99 percent of the total variation in the DOC surface water data (Table 4-5, Figure 4-9). The season factor was the greatest contributor to variability in DOC accounting for 3.36 percent of the variability. There was a maximum mean value of 2.17 mg/L for DOC in the summer season. This phenomenon is explained by the high biological productivity of the ponds during the summer months that increases the concentration of DOC in the surface water. Otherwise, there was no other significant difference explained by the model for the class, phase, or limnion factors. Effects of DOC on the surface water by the ETR system was not indicated in this analysis.

4.3.2 Ecological Criteria Guideline Evaluation: Tier I Parameters

A series of two-sample tests was conducted comparing study pond surface water to reference pond surface water. These tests were conducted using Tier I parameters of temperature, pH, DO, and DOC. The data populations were first divided into Phase I

and Phase II components and then analyzed as study pond, Snake, compared to reference ponds, Peters and Triangle (Table 4-6, Figures 4-10 and 4-11).

4.3.2.1 Phase I Evaluation

Phase I data were more than adequate with 28 to 270 observations for any one category. This large data set allowed the use of parametric t-tests to assess the difference between the means of the study and reference surface water and made for a more reliable assessment of significant differences.

Two-Sample Test Results. The results of the Phase I comparison indicate that there was a statistically significant difference between the downgradient and reference surface water for three of the Tier I parameters, pH, temperature, and DO (Table 4-6, Figures 4-10 and 4-11). The pH and temperature of the study pond were lower than that of the reference ponds, while the DO was higher. None of these is considered to be of negative impact on the ecosystem because (1) the ETR is known to raise the pH levels of treated water not lower them, (2) the ETR system cannot cool groundwater prior to reinjection, and (3) a high DO value means the water is saturated with oxygen, a desirable effect for the organisms inhabiting the pond.

Ecological Criteria Guideline Results. The Phase I evaluation shows that two of the Tier I parameters, DOC and temperature, exceeded the ecological criteria guidelines (Table 4-6, Figures 4-10 and 4-11). These exceedences are not attributable to the ETR and are more representative of the natural variation because they were collected prior to the start-up of the ETR.

Phase II Evaluation. Phase II data were more than adequate with 34 to 444 observations for any one category. This large data set allowed the use of parametric t-tests to assess the difference between the means of the study and reference surface water and made for a more reliable assessment of significant differences.

Two Sample Test Results. The two-sample tests that were performed on Phase II surface water data showed only one statistically significant difference between means (Table 4-6). The mean pH for the reference surface water was significantly higher than the study surface water by 0.41 pH units. The means of the remaining Tier I parameters showed no significant difference between reference and study surface water.

Ecological Criteria Guideline Results. An analysis of the ecological criteria guidelines for Phase II surface water Tier I parameters showed that no guidelines were exceeded (Table 4-6, Figures 4-10 and 4-11). All parameters were well within the limits of 20 percent and two standard deviations. Therefore, according to these results, the FS-12 ETR has had no effect on the surface water Tier I parameters in Snake Pond.

4.3.3 Physicochemical Parameters

Summary statistics for several field and physicochemical parameters in surface water are presented in Table 4-4. These parameters include ORP, specific conductance, turbidity, TSS, TDS, total organic carbon (TOC), alkalinity, and dissolved inorganic carbon (DIC). Maximum detected physicochemical parameters for surface water can be found in Appendix H-2.

4.3.4 Chemical Parameters

A water quality screen was performed for Ecotox threshold (EPA 1996) for surface water samples at Snake Pond, Peters Pond, and Triangle Pond collected in 1998 (Appendix H-2). There were two exceedences of Ecotox thresholds for barium (3.9 μg/L) at Snake Pond. Sample ECSNP08 had an exceedence for barium of 4.95 μg/L (May 1998) and sample ECSNP07 had an exceedence for barium of 5.31 μg/L (May 1998). There were no other exceedences for surface water. Results of the water quality screen are presented in Appendix H-2.

4.4 BIOLOGICAL RESULTS

4.4.1 Phytoplankton

A generalized pattern of the dominant phytoplankton succession in ponds throughout the year involves the following: (1) low-light and low temperature adapted microflagellates in winter, (2) spring bloom of diatoms, (3) summer bloom of chlorophytes (green algae), and (4) late summer to early fall bloom of either diatoms in relatively nonproductive lakes or cyanophytes (blue-green algae) in eutrophic lakes (Mandaville 1997).

Three genera (chlorophyta, chrysophyta, and cyanophyta) dominated the phytoplankton community of Snake, Triangle, and Peters ponds from late spring to late summer 1998. Samples collected in September from Snake and Triangle ponds contained the highest average concentration of phytoplankton measured in the photic zone in 1998 (7,005 and 23,321 cells/mL respectively). The highest average phytoplankton photic zone concentration in Peters Pond (10,862 cells/mL) was measured in June 1998.

Cyanophyta (blue-green algae) was the dominate genus in the phytoplankton community of (1) Snake Pond in May, August, and September 1998 (Figure 4-12); (2) Triangle Pond during June, August, and September 1998 (Figure 4-13); (3) and Peters Pond in May and September 1998 (Figure 4-14). The emergence of cyanophyta domination in the phytoplankton community in 1998 was most likely because of a change in climatic conditions, such as the milder winter and warmer spring. However, in 1997 cyanophyta was the dominant genus in the phytoplankton community in Triangle Pond (52 percent) during August (Figure 4-15). The maximum relative abundance of cyanophyta in 1997 was 5 percent in Snake Pond and 24 percent in Peters Pond (Figures 4-16 and 4-17).

There is a discrepancy in the sampling techniques between the late spring and late summer 1997 and 1998. This resulted in differential distributions of phytoplankton

genera in Snake Pond and the reference ponds between 1997 and 1998. In 1997, phytoplankton samples were collected from a single depth of three feet. In 1998, phytoplankton samples were collected from three depths to characterize the photic zone (Section 3.5.1). The 1998 sampling strategy reflects a comprehensive view of the phytoplankton community throughout the photic zone during each sampling event. Climatic differences between 1997 and 1998 affected the phytoplankton genera distribution observed in the ponds. These differences included a significantly colder 1996-1997 winter and 1997 spring than the 1997-1998 winter and 1998 spring when air temperatures reached into the 70s °F. The effect of the warmer than usual winter and spring could have caused an earlier spring phytoplankton bloom and an extended growing season. This climate difference would affect the availability of micronutrients such as nitrate, nitrite, and ammonium in the epilimnion. Several genera of phytoplankton have preferences for the various forms of inorganic nitrogen species in the epilimnion. As inorganic nitrogen becomes depleted from the epilimnion, usually in late summer, certain species of cyanophyta have the ability to utilize dissolved atmospheric nitrogen (nitrogen gas). These species tend to dominate in the late summer months.

Three types of indices, richness, evenness, and diversity, were calculated using phytoplankton data collected in 1998. The indices calculated for Snake Pond were compared to the indices for Triangle and Peters ponds. Richness indices, Gleason's, Margalef's, and Menhinick's indices, relate the number of species identified from each pond. The greater number of species identified in a pond the richer the ecosystem. The indices indicate that Peters Pond is richer in the number of phytoplankton species than Snake Pond, followed by Triangle Pond (Tables 4-7 through 4-10). The evenness index is a measure of the distribution of individuals in the taxa identified in the pond. The evenness index results indicated that Peters Pond had a more uniform distribution of taxa than Snake Pond followed by Triangle Pond (Tables 4-7 through 4-10). Diversity indices (i.e., Simpson's and Shannon's index) combine the measure of richness and evenness. The diversity indices indicated that

Peters Pond was more diverse than Snake Pond followed by Triangle Pond (Tables 4-7 through 4-10).

The richness, evenness, and diversity indices calculated for phytoplankton samples collected from late spring through late summer 1998 indicate a greater variability between the ponds than within the ponds (Table 4-10). The 1997 data indicated a greater variability within the ponds than between them. The decrease in variability within the ponds was a result of the sampling procedure used in 1998, characterizing the photic zone rather than the top three feet of the epilimnion. Differences observed between the 1997 and 1998 data occurred in both the study and reference ponds. This investigation determined that the differences were related mainly to the sample technique used and climatic differences between 1997 and 1998. The differences observed in the phytoplankton population between 1997 and 1998 were not caused by the operation of the FS-12 groundwater treatment system.

4.4.2 Zooplankton

The 1998 zooplankton investigation was characterized by a change in the sampling strategy. In 1997, zooplankton samples were collected from one depth (3 ft) to characterize the epilimnion. Because of the mobility of zooplankton, net tows were used in 1998 to collect samples throughout the water column.

Because phytoplankton are the principal food source for zooplankton, zooplankton concentrations and speciation are related to phytoplankton concentrations and speciation. Zooplankton concentrations were similar within ponds throughout the summer. Peters Pond had the lowest concentration of zooplankton (0.0016 - 0.0019 organisms/mL), followed by Triangle Pond (0.0025 – 0.0036 organisms/mL) and Snake Pond (0.0023 – 0.0081 organisms/mL). Zooplankton speciation for Snake, Triangle, and Peters ponds are presented in Figures 4-18 through 4-20.

Three types of indices, richness, evenness, and diversity, were calculated using zooplankton data collected in 1998. The indices calculated for Snake Pond were

compared to the indices for Triangle and Peters ponds. Richness indices, Gleason's, Margalef's, and Menhinick's indices, relate the number of species identified from each pond. The greater number of species identified in a pond, the richer ecosystem. The indices indicate that Peters Pond is richer in the number of zooplankton species than Snake Pond, followed by Triangle Pond (Tables 4-11 through 4-14). The evenness index is a measure of the distribution of individuals in the taxa identified in the pond. The evenness index results indicated that Peters Pond had a more uniform distribution of taxa than Triangle Pond followed by Snake Pond (Tables 4-11 through 4-14). Diversity indices, Simpson's and Shannon's indices, combine the measure of richness and evenness. The diversity indices indicated that Peters Pond was more diverse than Triangle Pond, followed by Snake Pond (Tables 4-11 through 4-14).

The richness, evenness, and diversity indices calculated for zooplankton samples collected during May, June, and August 1998 were unable to assess whether there was greater variability within the ponds or between the ponds. The zooplankton indices calculated for the September 1998 sampling round exhibits greater variability within than between the ponds. Data collected in 1997 indicated there was more variability within than between the ponds. The differences between the 1997 and 1998 indices were the result of changes in the sampling strategy and climatic conditions. The operation of the FS-12 groundwater treatment system had no affect on the Snake Pond zooplankton community.

4.4.3 Benthic Macroinvertebrates

Benthic macroinvertebrate samples were collected twice, in June and September, from Snake, Triangle, and Peters ponds in 1998 (Figures 4-21 through 4-23). There was a change in the sampling strategy between 1997 and 1998. In 1997, benthic macroinvertebrate sample locations were co-located with surface water sample locations, and the benthic macroinvertebrates were collected in triplicate. In 1998, ten benthic macroinvertebrate sample locations were chosen per pond, based on the most common sediment substrate and depth. Benthic macroinvertebrate samples were not collected from locations within the hypolimnion. Sample locations within

the hypolimnion were eliminated because organisms were stressed by environmental conditions such as low DO concentrations or anoxic conditions in late summer and reducing conditions in the sediment.

Benthic macroinvertebrate samples collected from Snake, Triangle, and Peters ponds in June and September 1998 were dominated by the insect order classification Diptera. Samples collected from these ponds in 1997 were also dominated by the order Diptera.

Three types of indices, richness, evenness, and diversity, were calculated using benthic macroinvertebrate data. The indices calculated for Snake Pond were compared to the indices for Triangle and Peters ponds. Richness indices, Gleason's, Margalef's, and Menhinick's indices, relate the number of species identified from each pond. The greater number of species identified in a pond, the richer ecosystem. The richness indices showed that Peters Pond is richer in the number of benthic macroinvertebrate species than Triangle Pond, followed by Snake Pond (Tables 4-15 through 4-18). The evenness index is a measure of the distribution of individuals in the taxa identified in the pond. The evenness index results indicated that Triangle Pond had a more uniform distribution of taxa than Peters Pond, followed by Snake Pond (Tables 4-15 through 4-18). Diversity indices, Simpson's and Shannon's indices, combine the measure of richness and evenness. In June 1998 the indices indicated that Triangle Pond was more diverse than Peters Pond, followed by Snake Pond. In September 1998 the indices showed that Triangle and Peters Pond had similar diversity, followed by Snake Pond (Tables 4-15 through 4-18).

The richness, evenness, and diversity indices calculated for benthic macroinvertebrate samples collected in June 1998 indicated a greater variability between than within the ponds. The indices calculated using data collected in September 1998 indicated a greater variability within than between the ponds. Data collected in 1997 indicated there was more variability within than between the ponds. The benthic macroinvertebrate indices showed a greater variability between the ponds in early summer and within the ponds in late summer. The differences in variability between

early and late summer were related to the life cycles of the dominant organisms in the ponds (insects) and insect predators.

Comparing the Phase I (1997) and Phase II (1998) benthic invertebrate data from Snake Pond and the reference ponds indicates that there has been no change in the community structure because of the operation of the FS-12 groundwater treatment system.

The percent difference of the concentration of the benthic macroinvertebrate community between Snake Pond (mean concentration 0.24 organisms/cm^2) and the reference ponds (mean concentration 0.31 organisms/cm^2) was 26 percent. The ecological criteria guideline value for the percent difference of the concentrations of the benthic macroinvertebrates between the study and reference ponds was 20 percent. Although this shows that benthic macroinvertebrates exceed ecological criteria guidelines, it can be demonstrated that the variability may not be attributed to the FS-12 ETR system. A two-sample test performed on the data set showed that there was no significant difference between the benthic macroinvertebrate population in Snake Pond in comparison to the reference ponds (Table 4-19).

The analysis of variance procedure performed on the benthic macroinvertebrate data showed that the season factor was the most significant contributor to the variability in the data set (Table 4-20). The season factor accounted for 35.3 percent of the variability with the summer season showing significantly higher concentrations of benthic macroinvertebrates (1.15 organisms/cm^2) in comparison to spring and fall (0.305 and 0.251 organisms/cm^2 respectively). The phase factor was a significant variant accounting for 6.83 percent of the variability in the data set. There were significantly more organisms in the ponds during the Phase I period than in Phase II, indicating that there may be some regional climatic phenomenon at work. The class factor only accounted for 0.003% of the variability in the data set and demonstrated that there was no significant difference in the benthic macroinvertebrate populations between Snake Pond and the reference ponds. This evidence indicated that the

variability in the data sets was attributed to factors other than the treatment system, and the exceedence of an ecological criteria guideline is not treatment system related.

4.4.4 Vegetative Communities

Plant cover measurements were estimated in the sample plots according to the cover classes referenced in the DEP Handbook (1995). Aquatic vegetation along the shoreline was identified, and relative cover estimates were determined. Information on the composition of the vegetative community was recorded on supplemental plant data forms.

Three transects were evaluated at Snake Pond (Figure 3-8). Because of the high surface water elevations at Snake Pond, the development of the coastal plain pondshore community along the shoreline of Snake Pond was sparse or absent. A similar absence was observed in the 1997 monitoring surveys performed at Snake Pond. When the vegetative monitoring program was initiated in the spring of 1996, the surface water elevation at Snake Pond was recorded on April 1, 1996 at 66.6 feet mean sea level (msl). A surface water level in excess of 72.3 feet msl was recorded in July 1998. This surface water elevation exceeded the previous high pond water level of 72.23 feet msl recorded in May 1974 (Letty 1984). The dramatic 5.6 ft increase in the pond elevation at Snake Pond over the monitoring period resulted in the complete or partial inundation of the transitional sample plots set out in 1996. All three transitional sample plots were originally located in the scrub wetland community above the exposed shoreline.

During the summer 1998 field surveys, the transitional sample plots at Snake Pond were fully or partially inundated by the high water level. Over 18 inches of water were recorded in the transitional plot located on the transect in the southwestern corner of Snake Pond. Aquatic sample plots, located in approximately 12 inches to 16 inches of water in the 1996 survey, were under approximately 3 to 4 feet of water in 1998. The increased pond level appeared to limit the development of the aquatic macrophyte community. The inundation of the transitional vegetation plots because

of the high surface water elevation resulted in a reduction in the estimated cover class for herbaceous species and the death of pitch pine (*Pinus rigida*) seedlings growing in the sample plots (Figure 4-24). Trace occurrences of soft rush (*Juncus effusus*), narrow-leaved goldenrod (*Euthamia tenuifolia*), and marsh fern (*Thelypteris palustris*) were recorded in the vegetative sample plots at Snake Pond.

Wetland shrub species tolerant of seasonal high water levels and saturated soil conditions, such as highbush blueberry (*Vaccinium corymbosum*), sweet pepperbush (*Clethra alnifolia*), and meadowsweet (*Spiraea latifolia*), exhibited no significant decline in abundance in the sample plots. In addition to the decline in the viability of the pitch pine seedlings in the pondshore environment, bayberry (*Myrica pensylvanica*) shrubs in the pondshore environment also exhibited signs of stress because of the high water level. The loss of the pitch pine seedlings in the coastal plain pond shore environment was particularly evident along the perimeter of Snake Pond and Weeks Pond viewed from Snake Pond Road.

The change in surface water elevation observed at Snake Pond during the three year monitoring period appears to fall within the natural cycle of water level fluctuations recorded at Snake Pond. The natural increase in the water level elevation altered the plant cover estimates recorded in the vegetative sample plots. Pitch pine and oak seedlings declined in number in the plant community. An aquatic macrophyte, bladderwort (*Utricularia* sp.), was recorded in two of the transitional plots because of the high surface water level.

The high surface water level covered the previously exposed pondshore environment resulting in a decline in species abundance and diversity in the coastal plain pondshore community. As the water level recedes in upcoming years, the species composition of the plant community should change to reflect the fluctuations in the pond level. Community diversity in the coastal plain pondshore community is maintained by regular fluctuations in the water level (Schneider 1994). Prolonged periods of flooding and drought are recognized as part of the normal hydrological regime observed in coastal plain pondshore communities (Barbour et al 1998). In

response to a short-term drawdown, the pondshore plant community becomes re-established on the exposed pondshore. Periods of long-term drawdown will allow pitch pine seedlings, oak seedlings, and other upland species to invade the upper margin of the pondshore and threaten species diversity in the pondshore environment.

The surface water elevation at Triangle Pond during the summer 1998 monitoring program also increased because of natural conditions. The field conditions observed at Triangle Pond in 1998 were similar to those observed at Snake Pond. The increase in the surface water elevation at Triangle Pond resulted in a decrease in the horizontal extent of the coastal plain pondshore environment. The transitional sample plots at Triangle Pond were both partially submerged for extended periods of time during the spring of 1998, as evidenced by water-stained leaves and driftlines. The high surface water elevation resulted in a decrease in the estimated cover class for herbaceous species and the dieback of young pitch pine seedlings recorded in the shrub category (Figure 4-25). The development of the aquatic macrophyte community was also limited at Triangle Pond due to the high surface water elevation. The submerged form of golden-pert (*Gratiola aurea* forma *pusilla*) was one of the few plants observed in the aquatic sample plots inspected at Triangle Pond.

The surface water elevation at Peters Pond did not exhibit a pronounced fluctuation in the water level. The wetland shrub community in the transitional sample plot exhibited signs of stress, such as the development of adventitious roots and enlarged lenticels at the base of the willow and red maple saplings, and on the bayberry shrubs in the single transitional sample plot established at Peters Pond. Pitch pine seedlings in the sample plot at Peters Pond exhibited signs of needle loss and dieback, while the bayberry shrubs exhibited leaf yellowing and leaf necrosis due to inundation. Herbaceous plants were absent, or present in trace amounts only, in the transitional sample plot. Water starwort (*Callitriche palustris*) and mats of needle-rush (*Eleocharis acicluaris*) were common in the aquatic sample plot. The estimated plant cover classes recorded in the 1998 survey were comparable to the estimated cover classes recorded in the 1997 survey at Peters Pond.

4.4.5 Threatened and Endangered Species

Meander surveys were performed in 1998 to document the presence of rare plants and animals in the coastal plain pondshore environment at the potential impact areas and reference areas. The following results summarize the rare plant and animal observations recorded in the 1998 surveys:

4.4.5.1 Snake Pond

Leaves (phyllodia) of slender arrowhead (*Sagittaria teres*) were recorded in the windrows of aquatic plant material on the shore of Snake Pond. Slender arrowhead is a special concern species (SSC). The parent plants were not observed, but are assumed to be present in mucky sediments in deeper water. No state-listed animals were recorded in the 1998 plant surveys. Rare dragonflies and damselflies have been recorded in the past at Weeks Pond, and it is highly probable that these species occur at Snake Pond.

4.4.5.2 Triangle Pond

The only state-listed plant species recorded at Triangle Pond was slender arrowhead (SSC). Watch List (WL) plant species recorded in the surveys were hyssop hedge-nettle (*Stachys hyssopifolia*) and annual umbrella sedge (*Fuirena pumila*). No state-listed animals were recorded at Triangle Pond in the 1998 surveys.

5.0 ECOLOGICAL IMPACT ASSESSMENT—TROPHIC STATE ANALYSIS

Pond or lake trophic status is the classification of a pond according to its degree of eutrophication (productivity). The trophic state assessment was performed to determine changes to the overall health of the study and reference ponds that could be related to the operation of the FS-12 ETR groundwater treatment system.

There are three general levels of productivity that classify trophic states: (1) oligotrophic (least productive), (2) mesotrophic, and (3) eutrophic (most productive). The classifications are relative and determined on the relative supply of nutrients, inorganic nitrogen and phosphorus to a pond or lake. The classifications are also related to the effects the increased nutrient loading has on the ecosystem, for instance, excessive growth of aquatic plants and phytoplankton, such as algal blooms. Ponds and lakes go through a natural eutrophication process, generally increasing in productivity as they age. Cultural eutrophication is the acceleration of the natural eutrophication process through increases in the supply of nutrients to a pond or lake by anthropogenic sources (e.g., septic systems). Eutrophic ponds are characterized by high concentrations of nutrients, high primary productivity, abundant macrophytes, a high density of phytoplankton cells, few algal species, common phytoplankton blooms, and low DO or anoxia in the hypolimnion. Mesotrophic ponds are characterized by moderate concentrations of nutrients, productivity, phytoplankton density, few macrophytes, diverse phytoplankton community structure, and moderate to low concentrations of DO in the hypolimnion. Oligotrophic ponds are characterized by low primary productivity, few macrophytes, low phytoplankton density, diverse phytoplankton community structure, and no depletion of oxygen in the hypolimnion.

5.1 SECCHI DEPTH

Secchi depth is a measure of light penetration into the water column. Turbidity, caused by the blockage of light by suspended solids or phytoplankton blooms,

reduces Secchi depth. The following relationships exist between Secchi depth and trophic status (NYDEC 1990):

- oligotrophic ponds: greater than 4.6 m
- mesotrophic ponds: 1.9 m - 4.6 m
- eutrophic ponds: less than 1.9 m.

Using Secchi depth to characterize trophic status, Snake, Triangle, and Peters ponds have Secchi depths typical of oligotrophic to mesotrophic conditions (Table 5-1).

5.2 NUTRIENT CONCENTRATIONS

Increased nutrient concentrations, especially phosphorous in freshwater systems, indicate a greater potential for eutrophication (EPA 1975). There are general guidelines regarding trophic status for orthophosphate and total phosphorous. The following relationship exists between phosphorous and trophic status (NYDEC 1990):

- oligotrophic ponds: less than 0.010 mg/L
- mesotrophic ponds: 0.010 mg/L—0.026 mg/L
- eutrophic ponds: greater than 0.026 mg/L.

Using total phosphorus concentrations to characterize trophic status, Snake Pond has a range of total phosphorous concentrations typical of oligotrophic to mesotrophic conditions. The reference ponds, Triangle and Peter, are in the oligotrophic range (Table 5-1).

5.3 CHLOROPHYLL *a*

Chlorophyll *a* concentrations are proportional to the concentration of phytoplankton in the water column. Eutrophic ponds generally have higher chlorophyll *a* concentrations. General relationships between mean summer chlorophyll *a* and trophic status can be described by the following (NYDEC 1990):

- oligotrophic ponds: less than 2 mg/L
- mesotrophic ponds: 2 mg/L—10 mg/L
- eutrophic ponds: greater than 10 mg/L.

Using chlorophyll *a* concentrations to characterize trophic status, Snake, Triangle, and Peters ponds fall in the range of oligotrophic to mesotrophic (Table 5-1).

5.4 PHYTOPLANKTON

Generally, mesotrophic and oligotrophic ponds have a more diverse phytoplankton community structure than eutrophic ponds. Cyanophytes tend to dominate eutrophic ponds either because of their affinity for high inorganic nitrogen concentrations or because of their ability to fix atmospheric nitrogen.

Three genera—chlorophyta, chrysophyta, and cyanophyta—dominated the phytoplankton community of Snake, Triangle, and Peters ponds from late spring to late summer 1998. Samples collected in September from Snake and Triangle ponds contained the highest concentration of phytoplankton measured in 1998 (7,005 and 23,321 cells/mL respectively). The highest phytoplankton concentration in Peters Pond was measured in June 1998 (10,862 cells/mL). Section 4.4.1 describes the phytoplankton genera collected during the 1998 sampling events.

Using the dominate phytoplankton genus to characterize the trophic status, Snake, Triangle, and Peters ponds fall in the range of mesotrophic to eutrophic (Table 5-1).

5.5 TROPHIC STATE INDICES

Limnologists often use Carlson's Trophic State Indices (TSI) (1977) to describe lake trophic status. This set of indices characterizes the trophic status of a pond using total phosphorus concentrations, chlorophyll *a* concentrations, and Secchi depth separately. These indices are uniformly scaled from 0 (oligotrophic) to 100 (eutrophic). When transformed to this trophic scale, the three parameters should yield similar TSI values. For best agreement between the indices, Carlson suggests that

data be collected from epilimnetic samples (samples collected from above the thermocline) during summer season when stratification occurs. A wide variation in the three indices at the same location indicates a discrepancy that requires further investigation. Carlson (1977) suggested, for the purposes of lake classification, that priority be given to the chlorophyll *a* index for summer data.

The TSI can be used for: (1) spatial comparative purposes, such as the regional classification of surface waters; (2) temporal comparisons, such as the pre- and post-implementation of a pond management program; and (3) to evaluate changes to the trophic state of the study pond relating to the operation of the ETR groundwater treatment system. The TSI is limited because it works well for northern temperate ponds that are phosphorus limited, but it works poorly for turbid ponds or ponds with excessive macrophyte growth (EPA 1990). This index does not consider how the influence of macrophyte levels, DO concentrations, turbidity, or other factors may affect the degree of eutrophication. The TSI should be used as part of a larger, integrated classification scheme that includes water chemistry and watershed analyses.

Table 5-1 presents the observed 1998 range of parameters used in the trophic state analyses for Snake, Triangle, and Peters ponds. Table 5-2 presents a summary of trophic state indices for Snake, Triangle, and Peters ponds, including the summers of 1996, 1997, and 1998. According to these indices that characterize trophic status, Snake Pond ranged from oligotrophic to meso-eutrophic based on the TSI values for total phosphorus, and Triangle and Peters ponds ranged from oligotrophic to mesotrophic. Snake Pond was mesotrophic based on the TSIs calculated for chlorophyll *a*, and Triangle and Peters ponds ranged from oligo-mesotrophic to mesotrophic. Snake, Triangle, and Peters ponds were mesotrophic based on the TSIs calculated for Secchi depth.

The TSIs calculated using 1998 epilimnetic total phosphorus concentrations were more consistent than the 1996 and 1997 indices. The consistence of the 1998 total phosphorus TSIs was a function of a change in the analytical methodology which

lowered the detection limit. In contrast, the 1996 and 1997 sampling activities used different analytical methods and the results were less consistent. The TSIs calculated for epilmnetic total phosphorus, chlorophyll *a*, and Secchi depth indicated that Snake Pond (study pond) and Triangle and Peters ponds (reference ponds) were mesotrophic. The comparison of Phase I and Phase II TSIs indicate that there has been no change in the trophic state of the study or reference ponds since the start-up and operation of the FS-12 ETR groundwater treatment system (Table 5-2).

The ecological criteria guidelines, which are used to evaluate the Phase I phytoplankton concentration measured by chlorophyll *a,* resulted in a 15 percent difference between Snake Pond (study pond) and the reference ponds. The percent difference between Snake Pond and the reference ponds for Phase II chlorophyll *a* concentrations was calculated to be 25 percent (Table 4-19). This difference exceeded the ecological criteria guideline value of 20 percent (AFCEE 1998c). However, there was no difference between the mean chlorophyll *a* concentration measured in Snake Pond for the Phase I and II sampling events (2.9 µg/L). The ecological exceedence for Phase II chlorophyll *a* was attributed to the decrease in the mean chlorophyll *a* concentrations measured in the reference ponds between the Phase I (2.4 µg/L) and Phase II (2.2 µg/L) sampling events.

Statistical analyses of the chlorophyll *a* data set for Snake Pond and the reference ponds indicated that the treatment system has had no effect on Snake Pond. The two-sample test did find a significant difference between the chlorophyll *a* concentration in Snake Pond in comparison to the reference ponds (Table 4-19). This difference in the means exceeded an ecological criteria guideline. The analysis of variance of the chlorophyll *a* data set (Table 4-20) indicated that the limnion factor was the most significant contributor to variability in the data set (12.6 percent). The season factor was also significant showing higher values in the spring in comparison to summer. The class factor showed no significant difference between the mean chlorophyll *a* concentrations in Snake Pond in comparison to the reference ponds and accounted for only 0.30 percent of the variability in the data set. These data indicated that, although

an ecological criteria guideline was exceeded, it is probable that the treatment system has had no effect on the chlorophyll *a* concentrations in Snake Pond.

6.0 RECOMMENDATIONS

6.1 GROUNDWATER

The Phase II groundwater Tier I parameters at the FS-12 ETR system were found, for the most part, to be within ecological criteria guidelines. One parameter, DOC, was found to exceed guidelines for the Phase II investigation. This exceedence was due to a lower concentration of DOC in the groundwater downgradient of the ETR system (0.5 mg/L) than the DOC concentration in the reference groundwater (0.8 mg/L). It is recommended that, although this could be a result of DOC removal by the ETR system prior to reinjection, this phenomenon be viewed as a positive effect because the system was designed to remove constituents like DOC. There is no need to adjust the ETR system to remain compliant.

The Phase I groundwater at FS-12 did exhibit a number of ecological criteria guideline exceedences. Three of the four parameters examined, DOC, temperature, and DO, exceeded guidelines as follows: (1) the DOC concentration in the groundwater was higher downgradient than in the reference groundwater, (2) the temperature was lower in the downgradient groundwater, and (3) the DO was higher in the downgradient groundwater. There are several ways to consider this information. Since these exceedences occurred prior to the start-up of the ETR system, these are not related to the ETR and are due to natural variation. It may be prudent to raise the ecological criteria guidelines for DOC, DO, and temperature. This could be accomplished by examining an upper confidence interval for comparisons between Phase I information for all studies. There is a recorded occurrence of natural fluctuations accounting for a 50 percent variation between reference and downgradient groundwater.

There may be a need to re-examine the ecological criteria guideline values as they may apply to groundwater. The groundwater upgradient of the FS-12 ETR system exhibited a 95 percent confidence level for the mean of ±0.61 ft difference. This would exceed the guideline value of ±0.5 ft established for surface water. The

upgradient well 90MW0020 is located up- and cross- gradient of the extraction well system. In contrast, the downgradient well 90MW0058, located adjacent to a reinjection well exhibited much less variability in water levels. It is believed that the upgradient groundwater level fluctuation is more like due to natural variation rather than due to drawdown by the extraction wells. Therefore, the ±0.5 ft limit may be too stringent a guideline to account for fluctuations that were naturally occurring and can be applied to the surface water ecological criteria guidelines. It is recommended that the ±0.5 ft guideline be increased to accommodate the natural fluctuations in the groundwater system. A ±1.0 ft confidence level would accommodate the natural variation observed in groundwater levels and may be a better estimate of artificial effects on the groundwater system, such as the mounding and drawdown due to an ETR system.

Use of statistical analyses may have to be refined to account for negative impacts by the ETR system. The original analyses test for differences in the means between study and reference groundwater. It may be possible to predict what negative impacts, if any, the ETR could have on Tier I parameters. For example, an increase in temperature that exceeds the ecological criteria guideline of 20 percent in the downgradient groundwater when compared to the reference groundwater could be viewed as a negative impact. On the other hand, a decrease in temperature in the downgradient groundwater could be viewed as no effect since the ETR system cannot cool ambient groundwater in the process. The use of a one-tailed test instead of a two-tailed test could provide the refinement necessary to describe exceedences possibly related to the ETR system instead of exceedences due to natural variation in the parameters.

The comparison of selected study groundwater wells with reference groundwater wells was affected by an unbalanced design. In many cases, there were four times as many study groundwater samples as there were reference groundwater samples. It is recommended that the number of reference groundwater samples be increased, perhaps by including designated reference groundwater wells from other plume

programs. For example, the reference groundwater used for the SD-5N ecological monitoring program would serve to increase the number of reference groundwater observations.

The analysis of the variance model that uses three factors may need modification. Currently there are three major factors being assessed for groundwater in these analyses as follows: (1) relative location, (2) season, and (3) phase. The model could account for only 17.84 to 46.49 percent of the variability in any Tier I parameter. Efforts to expand the model to account for more variability may be needed to help explain more of the variability in the data set.

There were no indicators that the FS-12 ETR system was having any affect on the downgradient ecosystems in terms of groundwater. Therefore, no adjustment to the ETR system is required because of groundwater exceedences.

6.2 PONDS

The ponds are one of the prime indicators of ecosystem health, and the assessment of ecological criteria guidelines must be fully understood. There were exceedences in the ecological guidelines for Phase I DOC (32.5 percent) and temperature (25.0 percent). Because these exceedences occurred prior to the start-up of the ETR system, the exceedences represent natural variability. The surface water of the reference ponds had more DOC and were warmer than the study ponds. These naturally occurring fluctuations in surface water parameters exceeded the 20 percent ecological criteria guidelines for DOC and temperature. Most of the variation, according to the analysis of variance procedure, was due to seasonal changes. If the seasonal changes have that much effect on the pond system, then it is recommended that these parameters be examined to raise the ecological criteria guideline limits to greater than 20 percent.

This practice of using DOC as a Tier I parameter for Phase I and II at all of the plume investigations has been questioned. DOC is often below detectable levels,

particularly in groundwater. The utility of DOC as a Tier I parameter is also questionable. DOC is not a source of energy for the primary producers (phytoplankton) but is a food source for bacteria which is produced by the natural decay of detritus, waste and decaying organisms. The ETR system is designed to remove DOC from the groundwater and should not be adjusted to increase the amount of DOC prior to reinjection. It is therefore recommended that DOC either be replaced by TOC (greater chance of detectable levels) or be eliminated as a Tier I parameter.

DOC in freshwater ecosystems is derived from a number of different sources. The two major sources of DOC include (1) photosynthetic inputs by flora through secretions and autolysis of cellular contents, and (2) allochthonous DOC composed primarily of terrestrially derived humic substances. Minor inputs of DOC into the ponds include excretions from fauna and bacterial chemosynthesis of organic matter (Wetzel 1983). It has been shown that concentrations of dissolved organic material in freshwater systems range from 0.1 to 50 mg/L. This dissolved organic material includes fatty acids, isoprenoids, alcohols, and other organic compounds (Cole 1994). Although DOC in groundwater may be a significant source, it is by far one of the lesser important sources of DOC in the ponds. The ecosystem in question, Snake Pond, averaged 1.48 mg/L in Phase I and 1.92 mg/L in Phase II. Although there is a decrease in DOC in groundwater downgradient of the treatment system, the ecosystem downgradient of the treatment system exhibits an increase in DOC in Phase II. The implication is that the removal of DOC from the groundwater is having minimal effect on the downgradient ecosystems.

The procedure to analyze variance of the surface water bodies at FS-12 used four factors instead of the three used for groundwater analysis. The model consisted of the following: (1) class, (2) season, (3) phase, and (4) limnion. The analysis of variance model accounted for 5.99 to 53.7 percent of the variability in the data sets for any one parameter. Results of the surface water model explained more variation than the groundwater model, therefore the surface water model may need to be revised to

explain the 46.3 percent variability in the surface water data set. It is recommended that other factors be considered to capture more of the variability in the Tier I parameters in these ponds. Other factors currently under consideration include (1) pond morphology, (2) groundwater flux, (3) pond flushing rate, and (4) biological activity.

The surface water data analysis may also consider use of one-tailed tests of significance for Tier I parameters instead of two-tailed tests. The procedure for analyzing ecological criteria guideline exceedences is organized so that an exceedence, whether attributed to the ETR system or not, is considered a potential effect of the ETR system. Positive effects, such as the removal of DOC from the groundwater, may be viewed as an exceedence that would justify adjustment of the ETR. It is recommended that potential affects on surface water bodies by the treatment system be analyzed, and one-tailed analyses be conducted to determine whether the treatment system is causing a detrimental affect on the ecosystem.

No ecological criteria guidelines were exceeded in the analysis of Phase II data. Therefore, it is recommended that no adjustment to the ETR system is necessary at FS-12.

6.3 BIOLOGICAL SURVEYS

The vegetative sampling surveys performed as part of the Ecological Studies Program during the past three years have established a comprehensive database for vegetation trends in the study areas and the designated reference areas. Based on the quantitative measurements collected to date, no additional vegetative monitoring work is proposed at Snake Pond.

Any change in the surface water level at Snake Pond because of the implementation of the FS-12 groundwater treatment system would be difficult to separate from the natural fluctuations in the surface water levels that have been recorded at Snake Pond. Prolonged periods of drought followed by periods of high water levels are part of the

normal hydrological regime in the coastal plain pondshore environment (Barbour et al 1998). Active groundwater treatment does not appear to have impacted the composition of the pondshore plant community. The fluctuations in the surface water level recorded over the past three years have been due to natural changes in the pond elevation. The water level fluctuations observed are within the normal water level cycles recorded for Snake Pond over a twenty-year period. These natural changes are significantly more dramatic than the potential change in surface water level that may occur because of the operation of the groundwater treatment system.

Future surveys of the monitoring operations will be based on rapid field assessments of the vegetative communities, and will be more efficient and productive. The surveys will provide a basis for determining potential adverse impacts to the coastal plain pondshore community at the impact areas in the Ashumet Valley and LF-1 plumes. Surveys proposed for the collection of baseline inventories at the Ashumet Valley and LF-1 plumes will continue. These vegetation surveys are designed to be less quantitative in nature and more qualitative. The qualitative assessment of the freshwater wetland systems will continue to document the presence of rare and threatened species. The qualitative assessment will also establish estimated densities for several key indicator species reflective of the general health of the pondshore community as a whole. Several of the primary reference areas will remain as control areas and will continue to be monitored.

After evaluating two years of biota data, i.e., phytoplankton, zooplankton and benthic macroinvertebrates collected from the study and the reference ponds, it has been determined that the Tier I parameters DO, temperature, and pH would be more sensitive measures of adverse ecological impacts because of the operation of the FS-12 groundwater treatment system. The Ecological Studies Program is recommending (1) using chlorophyll *a* concentrations as a measure of phytoplankton concentrations and (2) eliminating zooplankton and benthic macroinvertebrate sampling. Benthic macroinvertebrates will be eliminated as a Tier II parameter.

6.4 TROPHIC STATE

Phytoplankton speciation and enumeration will not be included in the trophic state analysis. The other trophic state parameters, Secchi depth, phosphorus, and chlorophyll *a*, will continue to be measured using the appropriate TSI.

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7.0 SUMMARY AND CONCLUSIONS

The Ecological Studies Program has investigated the ecosystems potentially impacted by the FS-12 ETR System. This investigation utilized information collected prior to the treatment system start-up (Phase I) and following the treatment system start-up (Phase II). The investigation included assessments of the surface water, groundwater, and biological communities. A comparison of the study surface water ecosystems to reference ecosystems has demonstrated that no adverse effects on the downgradient surface water ecosystems can be attributed to the FS-12 treatment system.

The groundwater study at FS-12 included examination of upgradient, downgradient, and reference groundwater. Groundwater elevations indicated that the downgradient groundwater was within the ±0.5 ft tolerance based on ecological criteria guidelines for surface water, but the upgradient groundwater exceeded guidelines by ±0.11 ft. Fluctuations in upgradient groundwater are not caused by the ETR system, but are attributed to the natural conditions of the groundwater environment. An analysis of variance procedure revealed that the season when the sample was collected was an important factor for predicting variability in the groundwater temperatures. The relative location, upgradient, downgradient, or reference, had a significant effect on pH, DO, and DOC, whereas downgradient groundwater was found to have higher pH levels, higher DO concentrations, and lower DOC levels.

Three Tier I parameters, DO, DOC, and temperature, exceeded ecological criteria guidelines during the Phase I investigation. The plant was not operational during Phase I and therefore could not cause the guideline exceedence. One parameter, DOC, exceeded ecological criteria guidelines for Phase II. The downgradient groundwater was significantly lower in DOC than that of the reference groundwater. If this is attributable to the ETR (the ETR does remove DOC prior to reinjection) it is not considered an adverse effect.

Groundwater samples collected for 1998 were screened against drinking water standards (DEP 1997) for chemical and physicochemical parameters (Appendix H-1).

A primary concern is an exceedence of EDB in Snake Pond microwell ECMWSNP02D of 0.029 μg/L from a sample collected in November. This exceedence may indicate that some plume contaminants were not captured by the FS-12 ETR and were transported into the downgradient groundwater. This reading in the microwell was noted, and further monitoring will determine whether this was an isolated event or an adjustment to the ETR system is necessary. The microwells in Snake Pond exhibited several exceedences for total metals. Total iron drinking water limits (300 μg/L) were exceeded for groundwater samples collected at ECMWSNP02D (1,360 μg/L—May 1998), ECMWSNP02S (7,850 μg/L—August 1998), ECMWSNP03D (1,950 μg/L—August 1998), and ECMWSNP03S (6340 μg/L—November 1998). Total nickel concentrations exceeded drinking water standards (100 μg/L) at Snake Pond microwell ECMWSNP02S (459 μg/L—August 1998). There was an exceedence of thallium drinking water standards (2 μg/L) at downgradient monitoring well 90MW0085B (3.2 μg/L—February 1998). The in-plume, upgradient groundwater monitoring well 90MW0020 showed drinking water exceedences of EDB (190 μg/L—January 1998), benzene (1,500 μg/L—January 1998), iron (1,270 μg/L—September 1998), and manganese (114 μg/L—September 1998).

The surface water monitoring for the FS-12 ETR concentrated on two study ponds (Snake and Weeks ponds) and two reference ponds (Peters and Triangle ponds). The analysis of pond water levels showed that there were no exceedences in mean pond elevation for any of the study or reference ponds. Weeks Pond showed the highest fluctuation level with a 95 percent confidence limit of ±0.28 ft. All surface water levels were within the ecological criteria guideline of ±0.5 ft. An analysis of variance procedure showed that the season factor was most important in accounting for the variability in temperature, DO, and DOC. This relationship is attributed to the nature of the ponds as open systems that are influenced by seasonal atmospheric changes. Two parameters, pH and DO, exceeded ecological criteria guidelines for Phase I. Because these parameters were exceeded during the Phase I event, the exceedences

are not attributed to the ETR system. There were no surface water ecological criteria guideline exceedences in Tier I parameters for Phase II when the ETR was operating.

A water quality screen was performed for Ecotox threshold (EPA 1996) for surface water samples at Snake Pond, Peters Pond and Triangle Pond collected in 1998 (Appendix H-2). There were two exceedences of Ecotox thresholds for barium (3.9 μg/L) at Snake Pond. Sample ECSNP08 had an exceedence for barium of 4.95 μg/L (May 1998) and sample ECSNP07 had an exceedence for barium of 5.31 μg/L (May 1998). There were no other exceedences for surface water.

The results observed in the Phase I and Phase II phytoplankton and zooplankton communities indicated the differences were the result of changes in climatic conditions and sampling strategies. Because similar results were observed in both the study and reference ponds, the differences between the 1996 – 1997 and 1998 phytoplankton and zooplankton communities are not attributed to the operation of the FS-12 groundwater treatment system. There was an ecological criteria guideline exceedence for Phase II chlorophyll *a* measurements between Snake Pond and the reference ponds. This exceedence was attributed to a decrease in chlorophyll *a* in the reference ponds in comparison to Snake Pond. Chlorophyll *a*, a Tier II parameter, was more stable in Snake Pond in comparison to the reference ponds. This exceedence was not attributed to the FS-12 ETR system.

The order Diptera dominated the benthic macroinvertebrate community in all ponds in 1997 (Phase I) and 1998 (Phase II). The benthic macroinvertebrate concentrations did exceed a Tier II ecological criteria guideline. There was a greater than 20 percent difference between the concentrations in Snake Pond in comparison to the reference ponds in Phase II. Statistical analyses showed that there was no significant difference and the season in which the sample was collected had the most significant effect on the variability in the data set. The statistical analysis of the data indicated the benthic macroinvertebrate community was not affected by the operation of the FS-12 groundwater treatment system.

The comparison of Phase I and Phase II TSIs indicate there has been no change in the trophic state of the study pond because of the operation of the FS-12 groundwater treatment system. There was no exceedence of the Tier II parameter for trophic state.

The vegetation around Snake Pond has been affected by a water table that was recorded approximately 5 ft higher in 1998 than in 1996. This elevated water level has resulted in a reduction of estimated cover class for herbaceous plants and the death of pitch pine *(Pinus rigida)* seedings. The elevated water levels have also promoted an increase in more hydrophyllic vegetation such as highbush blueberry (*Vaccinium corymbosum*), sweet pepperbush (*Clethra alnifolia*), and meadowsweet (*Spiraea latifolia*). This high water table is representative of a natural fluctuation in water levels that commonly occurs in the area. Leaves of slender arrowhead (*Sagittaria teres*), a species of special concern (SSC), were recorded at Snake Pond and Triangle Pond. Watch List (WL) plant species recorded in the surveys were hyssop hedge-nettle (*Stachys hyssopifolia*) and annual umbrella sedge (*Fuirena pumila*). No state listed animals were recorded at any of the ponds.

In summary, there was little evidence to attribute significant changes in the downgradient ecosystems at FS-12 to the ETR system. No adverse effects have been determined for the 1998 annual assessment.

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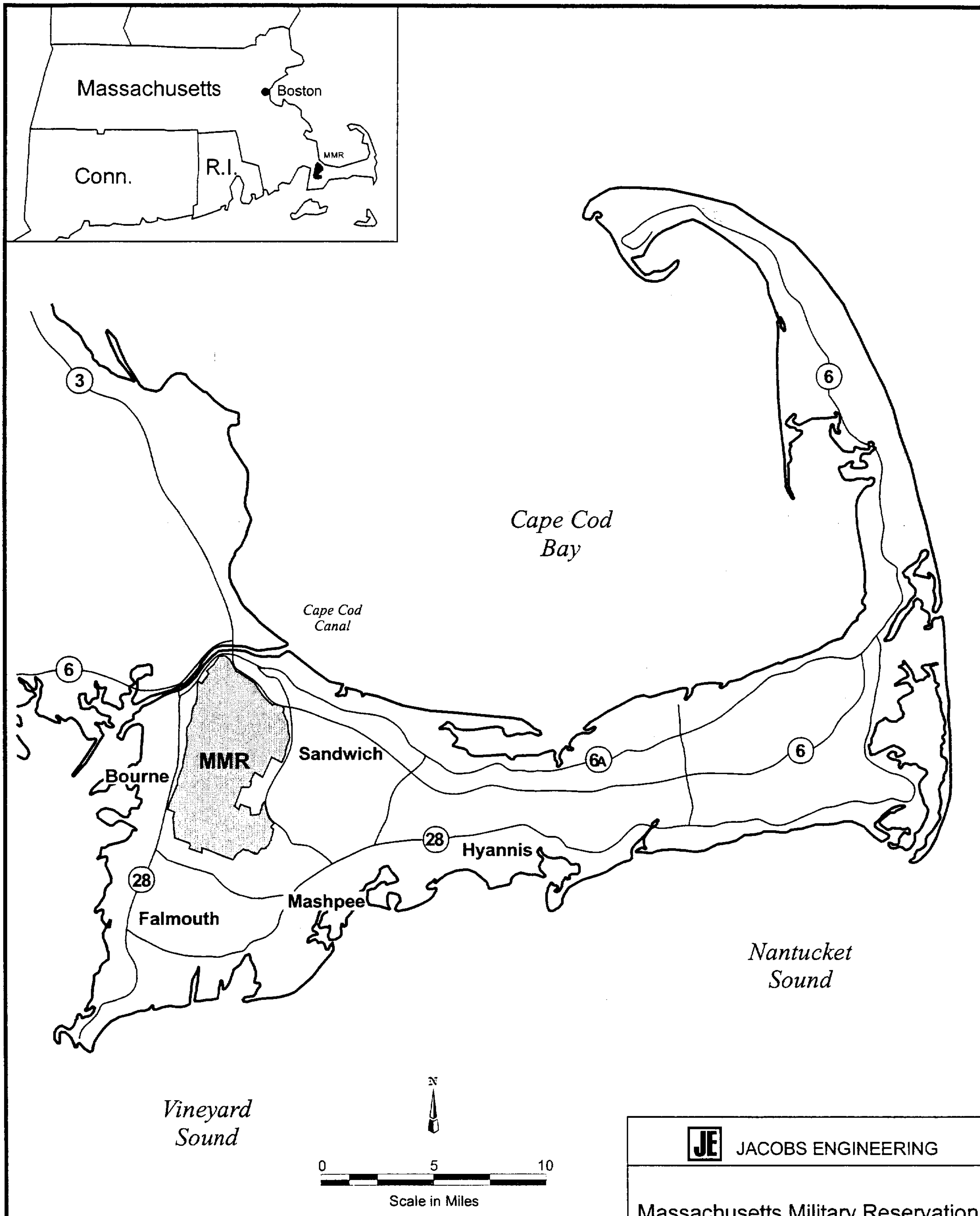
FIGURES



Massachusetts Military Reservation
Cape Cod, Massachusetts

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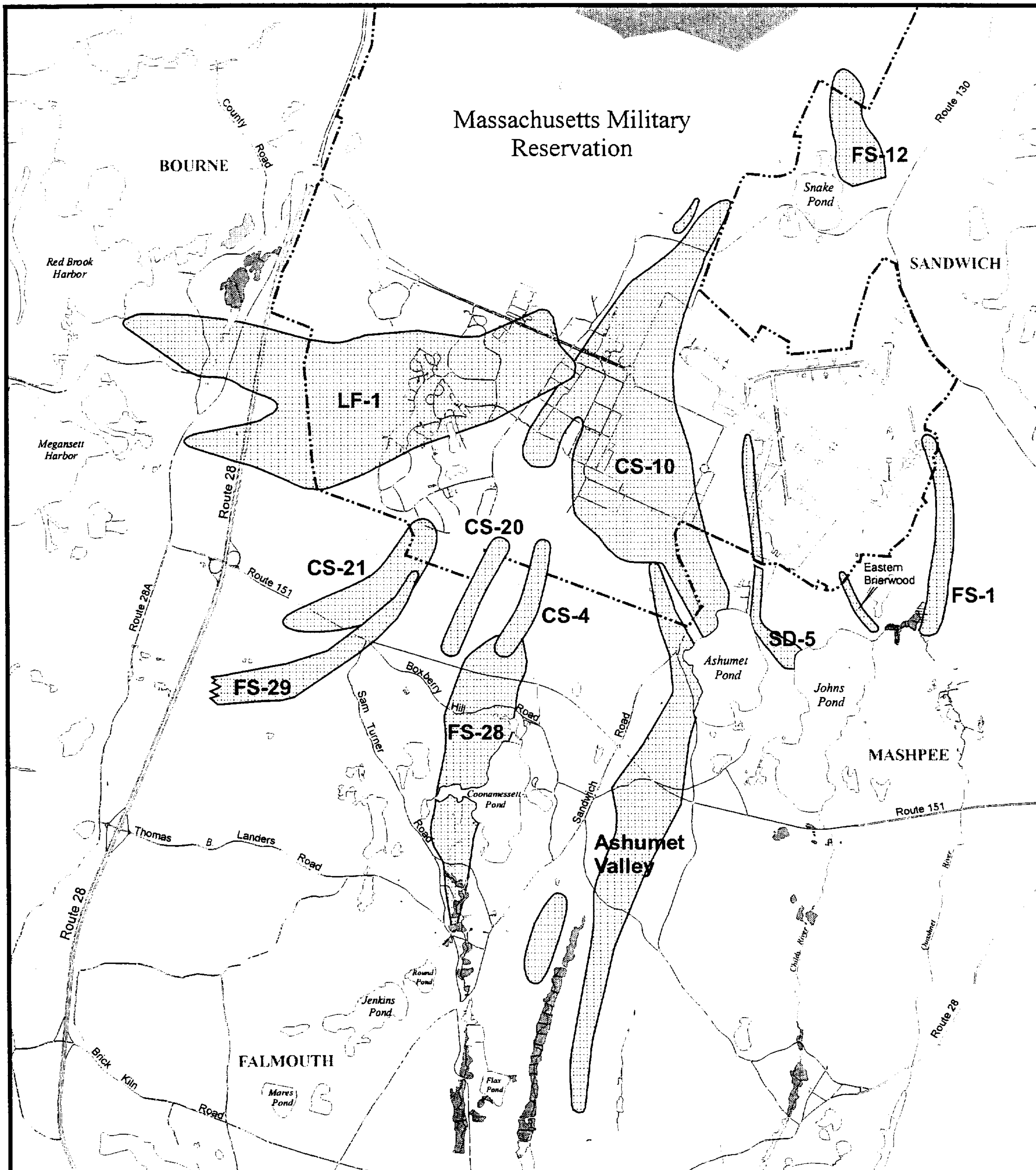
Figure 1-1



Legend

Plume Contour

MMR Boundary

Pond

N

0 3000
Scale in Feet

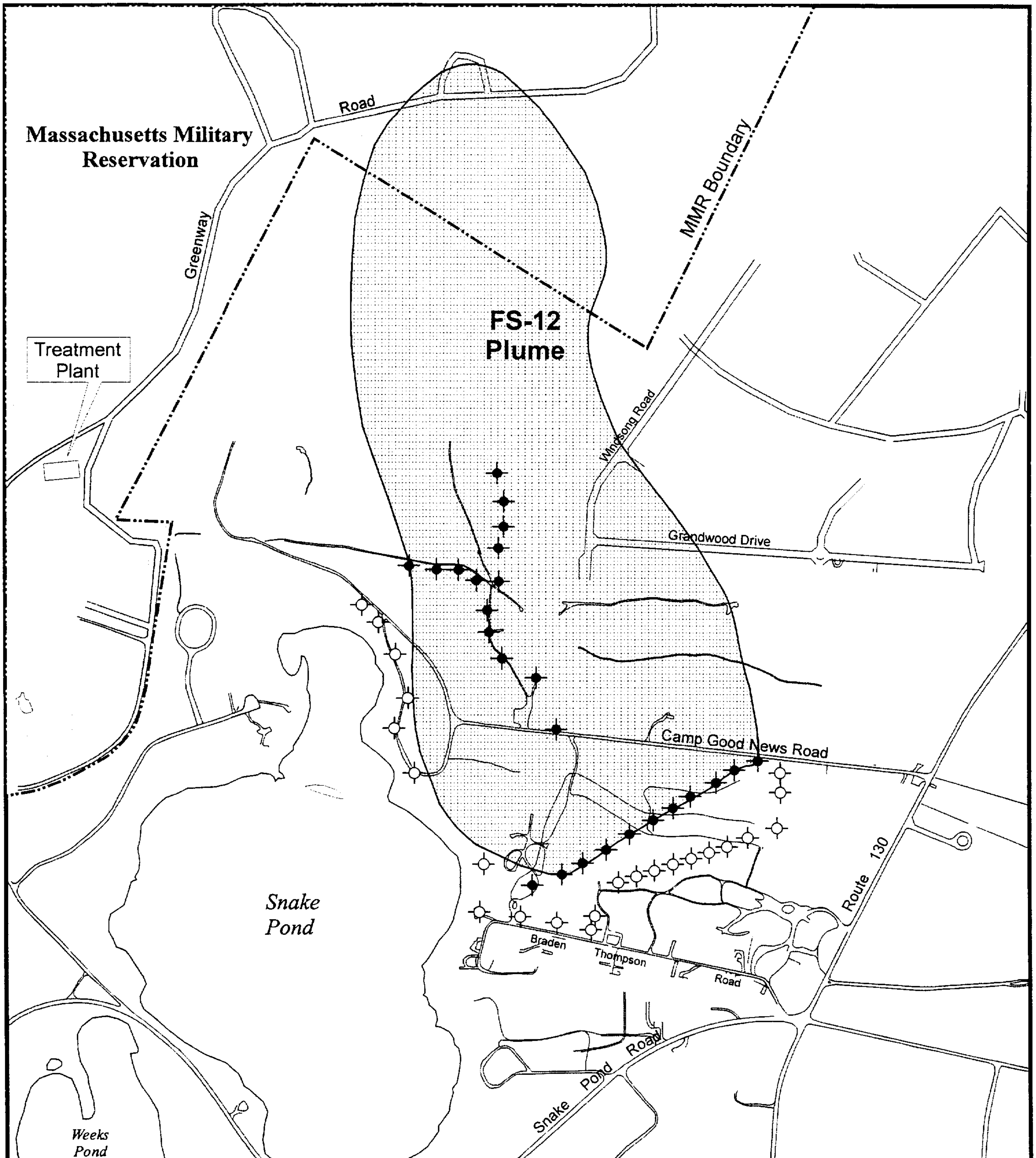
JACOBS ENGINEERING

Plume Area Map
January 1999

Massachusetts Military Reservation
Cape Cod, Massachusetts

12/4/98 kk fs12_PL98.cdr

Figure 2-1



Legend

- Plume Contour
- Extraction Well
- Reinjection Well

0 750
Scale in Feet

JE JACOBS ENGINEERING

FS-12 Plume
November, 1998

Massachusetts Military Reservation
Cape Cod, Massachusetts

3/18/99 kk f12&JPAT1.cdr	Figure 2-2

Legend

- ▲ Indicates Potentially Impacted Site
- ■ Indicates Reference Areas
- MMR Boundary
- Plume Boundary

N

0 3000

Scale in Feet

JE JACOBS ENGINEERING

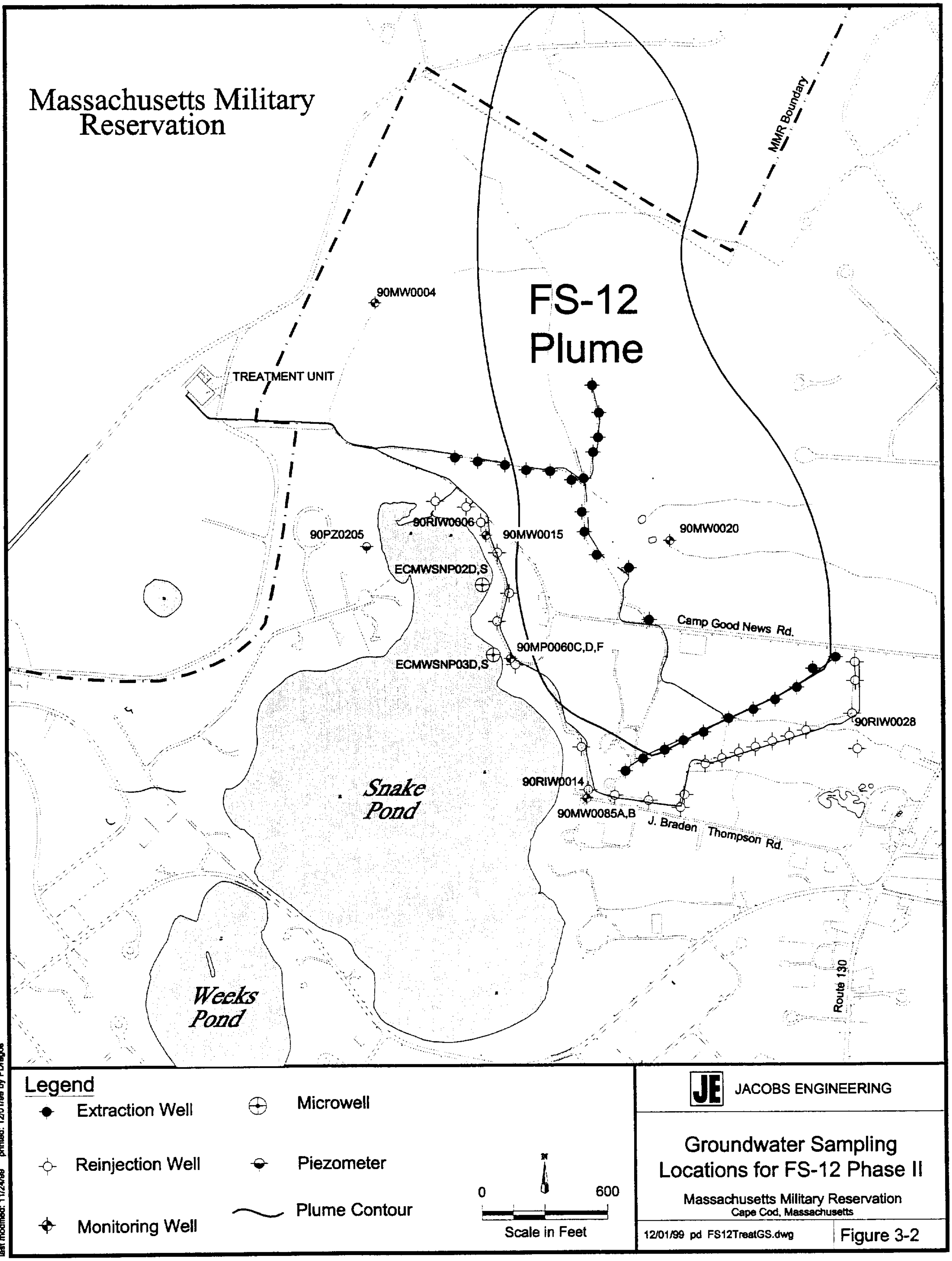
Study and Reference Areas Associated with the FS-12 Phase II ESP

Massachusetts Military Reservation

Cape Cod, Massachusetts

4/27/99 SC File: FS12-01.CDR

Figure 3-1



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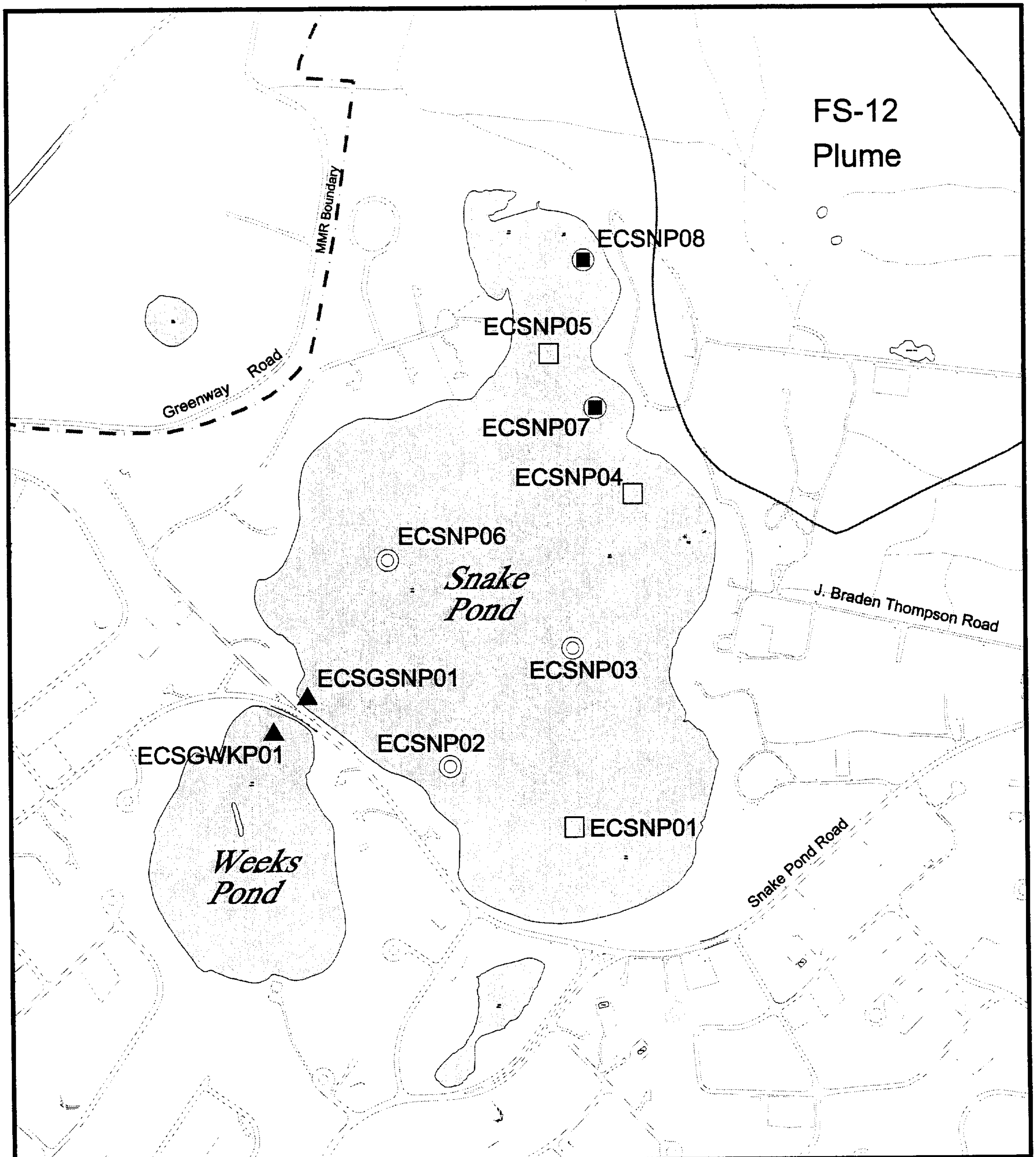

Legend

- Surface Water Chemical Sampling Location
- Previously Sampled Location
- Surface Water Physical and Physicochemical Sampling Location
- Staff Gauge

0 600
Scale in Feet

JE JACOBS ENGINEERING

Snake Pond
Sample Locations
Potentially Impacted Site
Massachusetts Military Reservation
Cape Cod, Massachusetts

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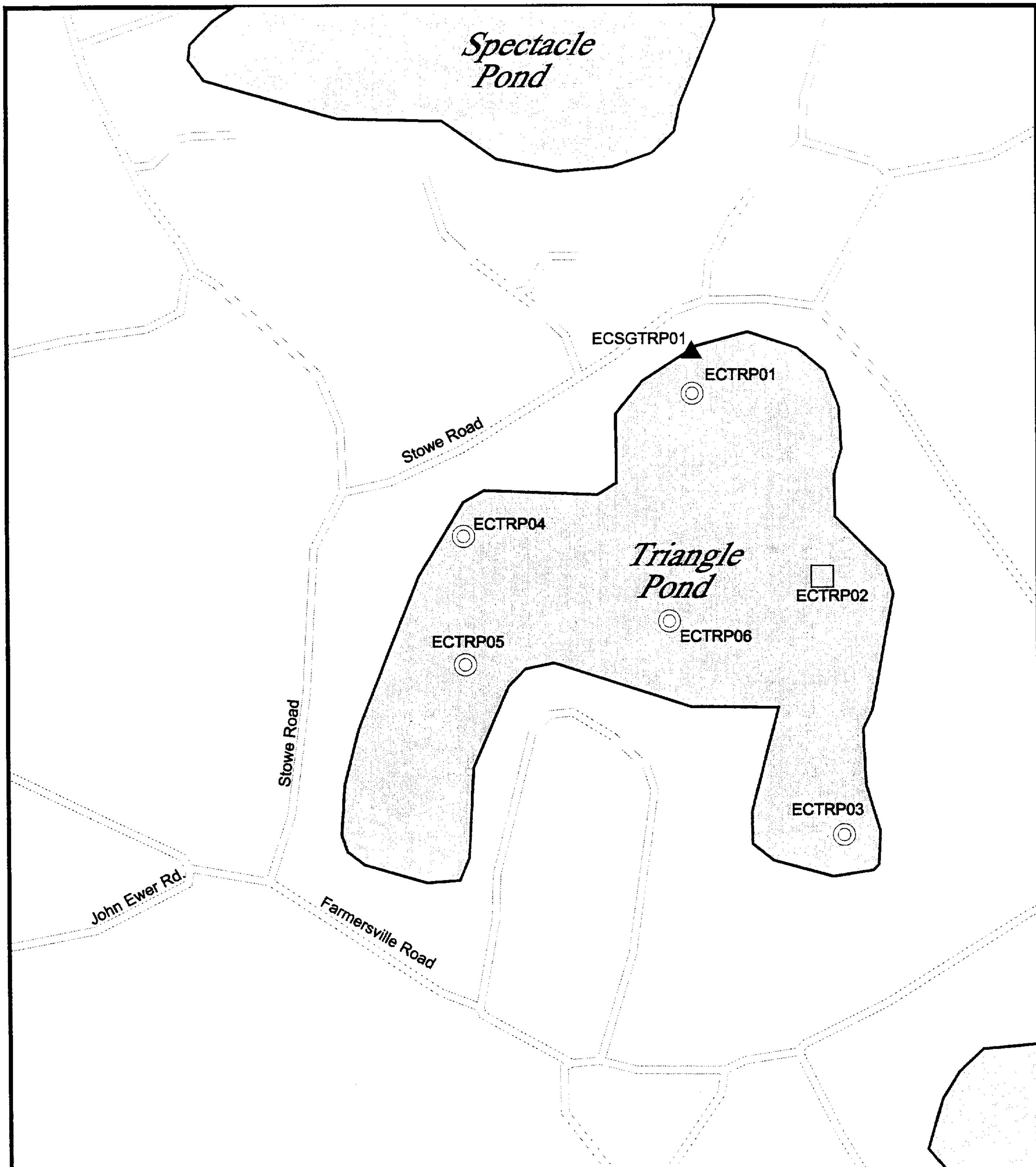


Legend

▲ Staff Gauge

◎ Surface Water Physicochemical Sample Locations

□ Previously Sampled Location

N

0 600

Scale in Feet

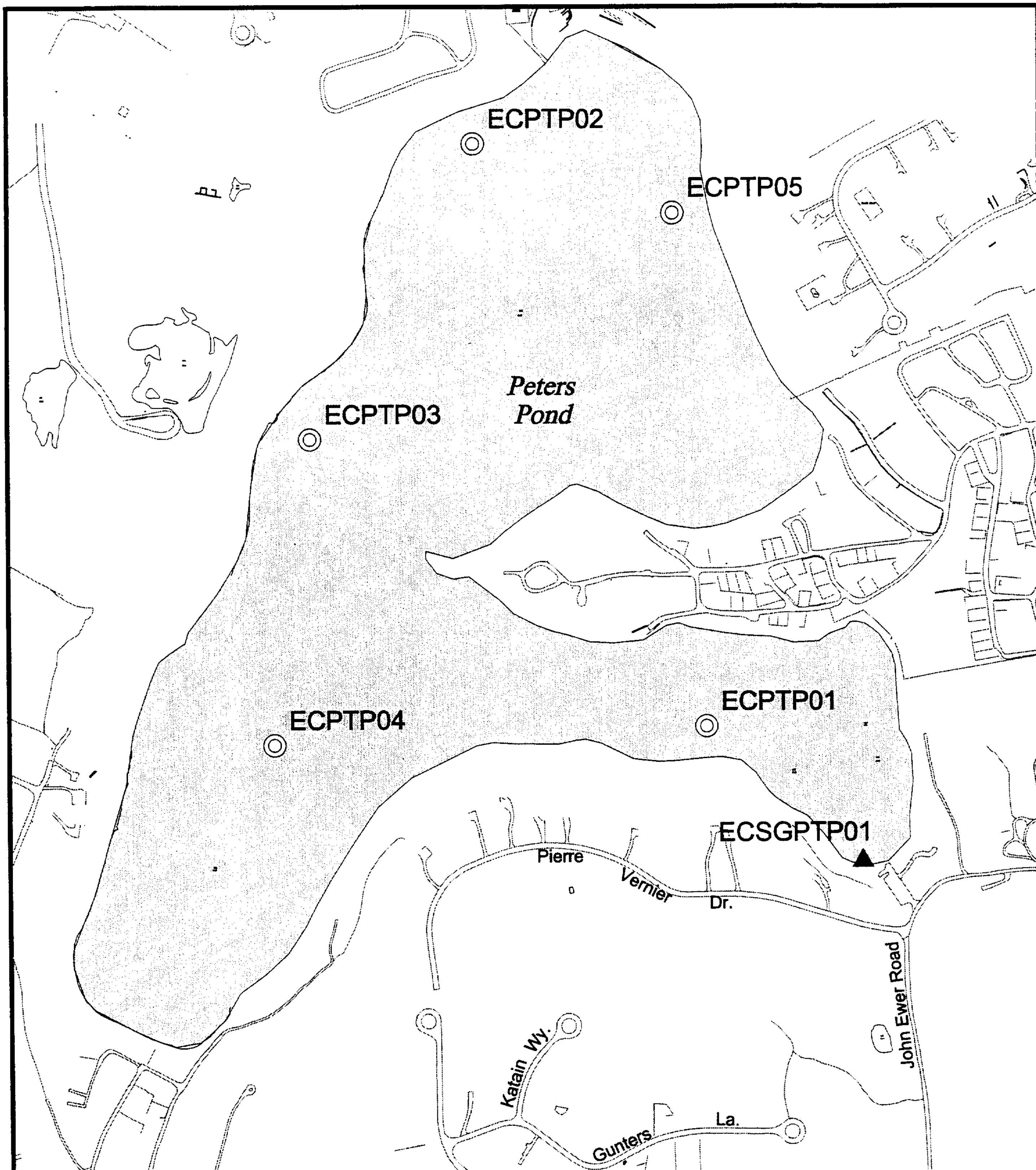
JE JACOBS ENGINEERING

Surface Water Sample Locations for the Triangle Pond Reference Area

Massachusetts Military Reservation
Cape Cod, Massachusetts

11/23/99 mm File...FS12treatTR.dwg

Figure 3-4



Legend

◎ Surface Water Physical and Physicochemical Sampling Location

▲ Staff Gauge

0 550

Scale in Feet

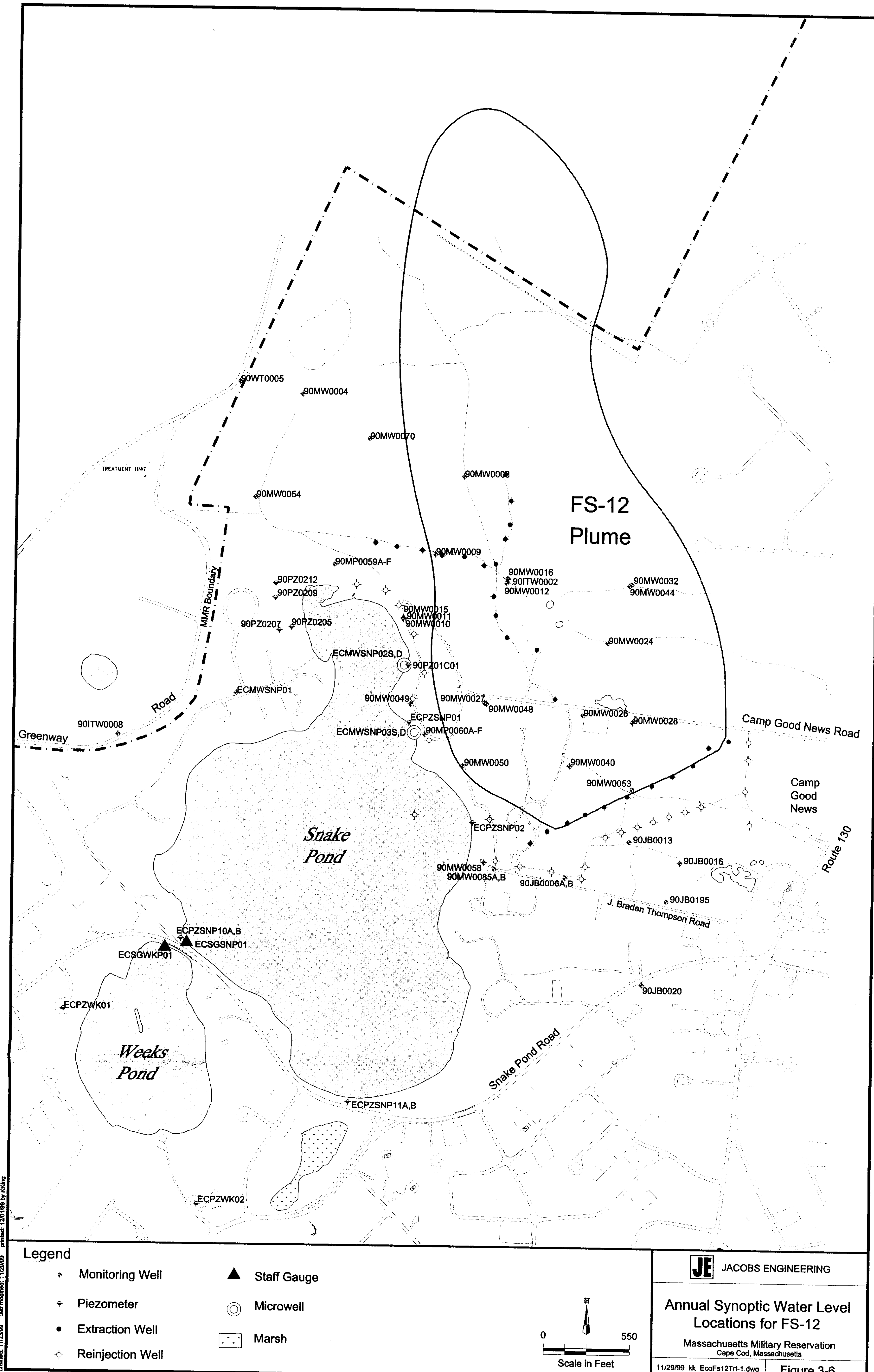
JACOBS ENGINEERING

Peters Pond Sampling Locations
Reference Area

Massachusetts Military Reservation
Cape Cod, Massachusetts

11/23/99 mm File...FS12treatPTPA.dwg

Figure 3-5

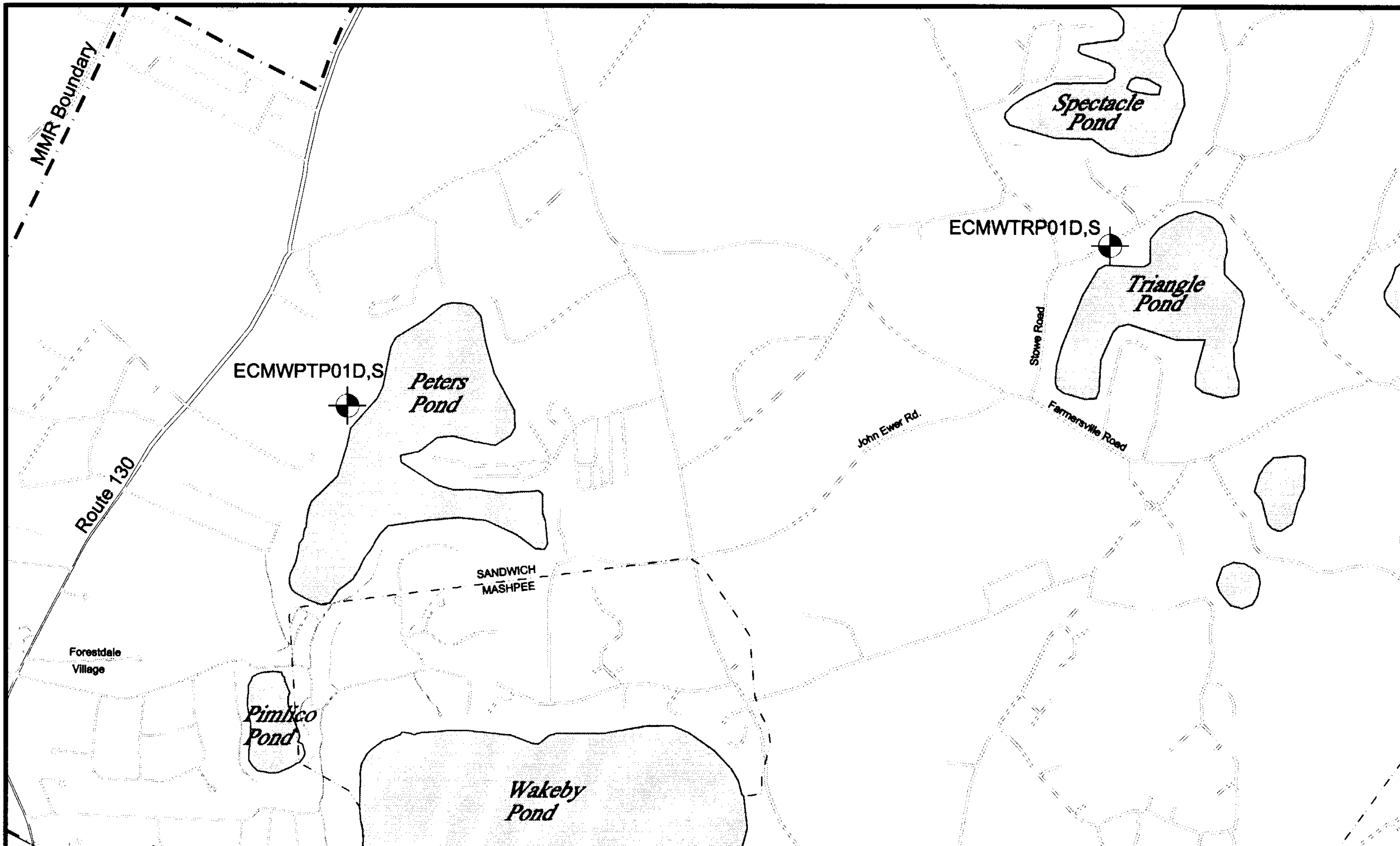


Annual Synoptic Water Level Locations for FS-12

Massachusetts Military Reservation
Cape Cod, Massachusetts

11/29/99 kk EcoFs12Trt-1.dwg

Figure 3-6



Legend

Monitoring Well

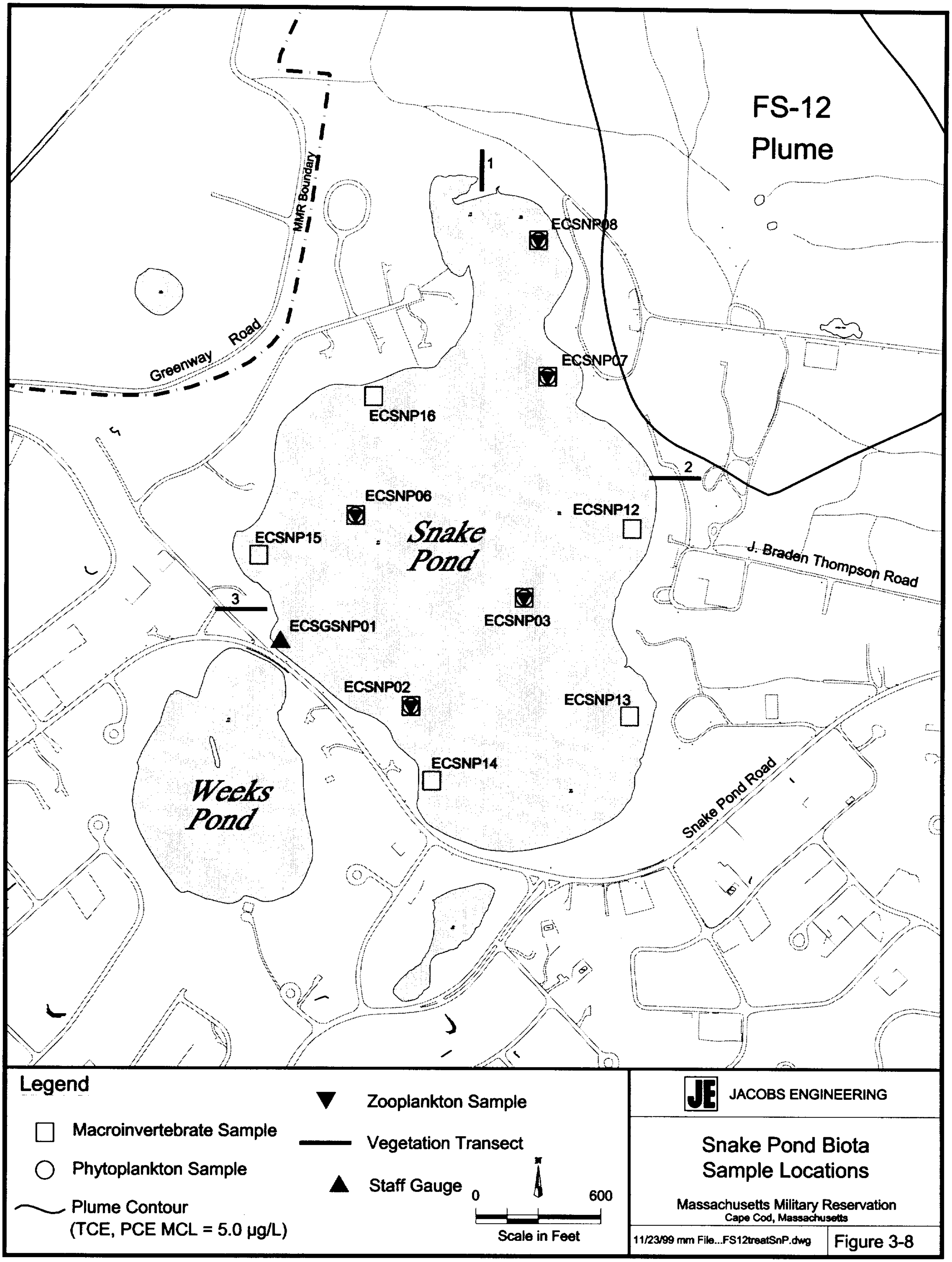
JACOBS ENGINEERING

FS-12 Phase II Groundwater Sample Locations

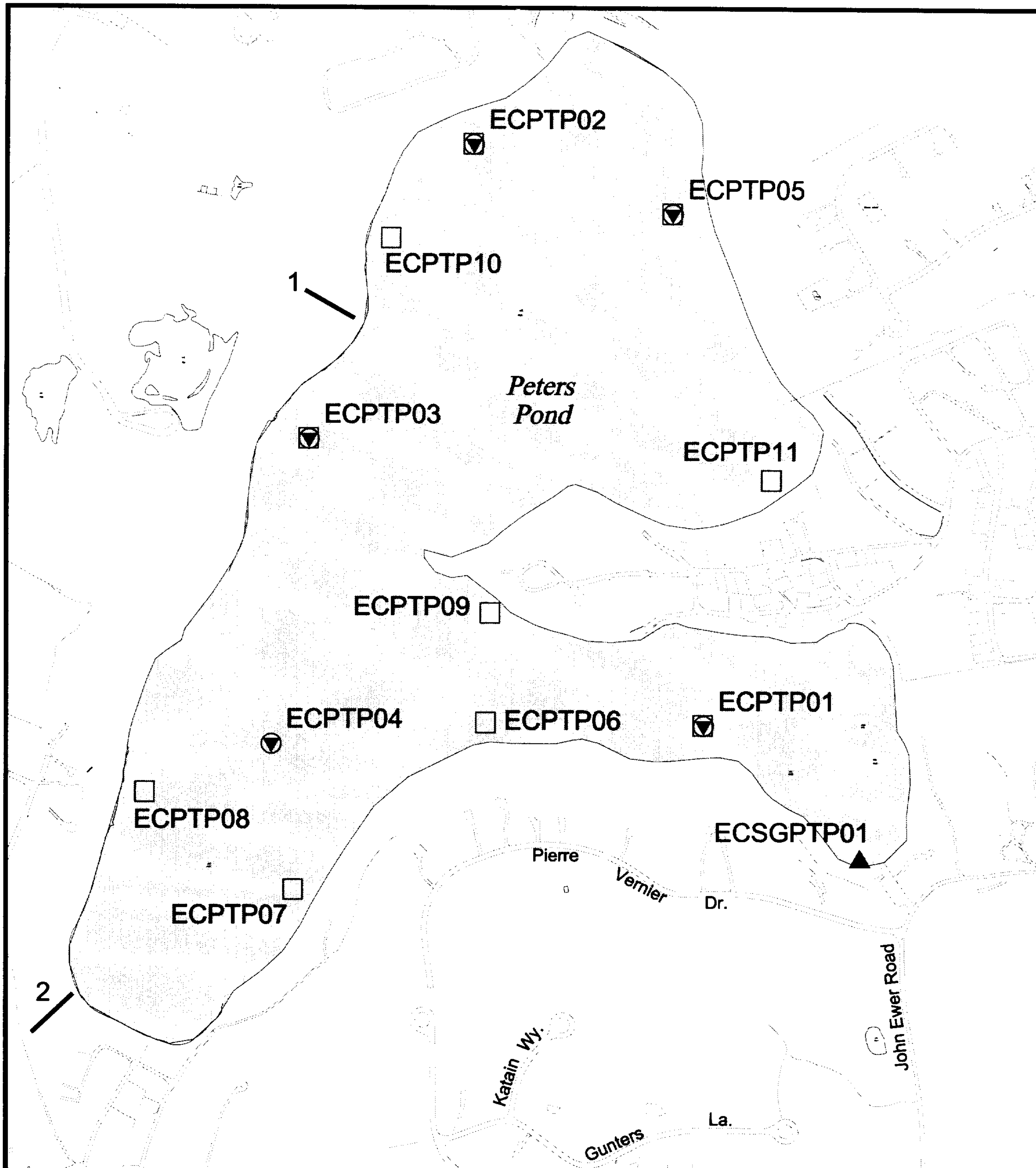
Massachusetts Military Reservation
Cape Cod, Massachusetts

11/24/99 mm File...FS12treatPII.dwg

Figure 3-7



FS-12
Plume
MMR Boundary
Greenway Road
1
2
3
ECSNP08
ECSNP07
ECSNP16
ECSNP06
ECSNP12
ECSNP15
Snake
Pond
J. Braden Thompson Road
ECSNP03
ECSGSNP01
ECSNP02
ECSNP13
ECSNP14
Weeks
Pond
Snake Pond Road
Legend
Macroinvertebrate Sample
Phytoplankton Sample
Plume Contour
(TCE, PCE MCL = 5.0 µg/L)
Zooplankton Sample
Vegetation Transect
Staff Gauge
0
600
Scale in Feet
JACOBS ENGINEERING
Snake Pond Biota
Sample Locations
Massachusetts Military Reservation
Cape Cod, Massachusetts
11/23/99 mm File...FS12treatSnP.dwg
Figure 3-8



Legend

- Macroinvertebrate Sample
- Phytoplankton Sample
- Staff Gauge
- Zooplankton Sample
- Vegetation Transect

0 550
Scale in Feet

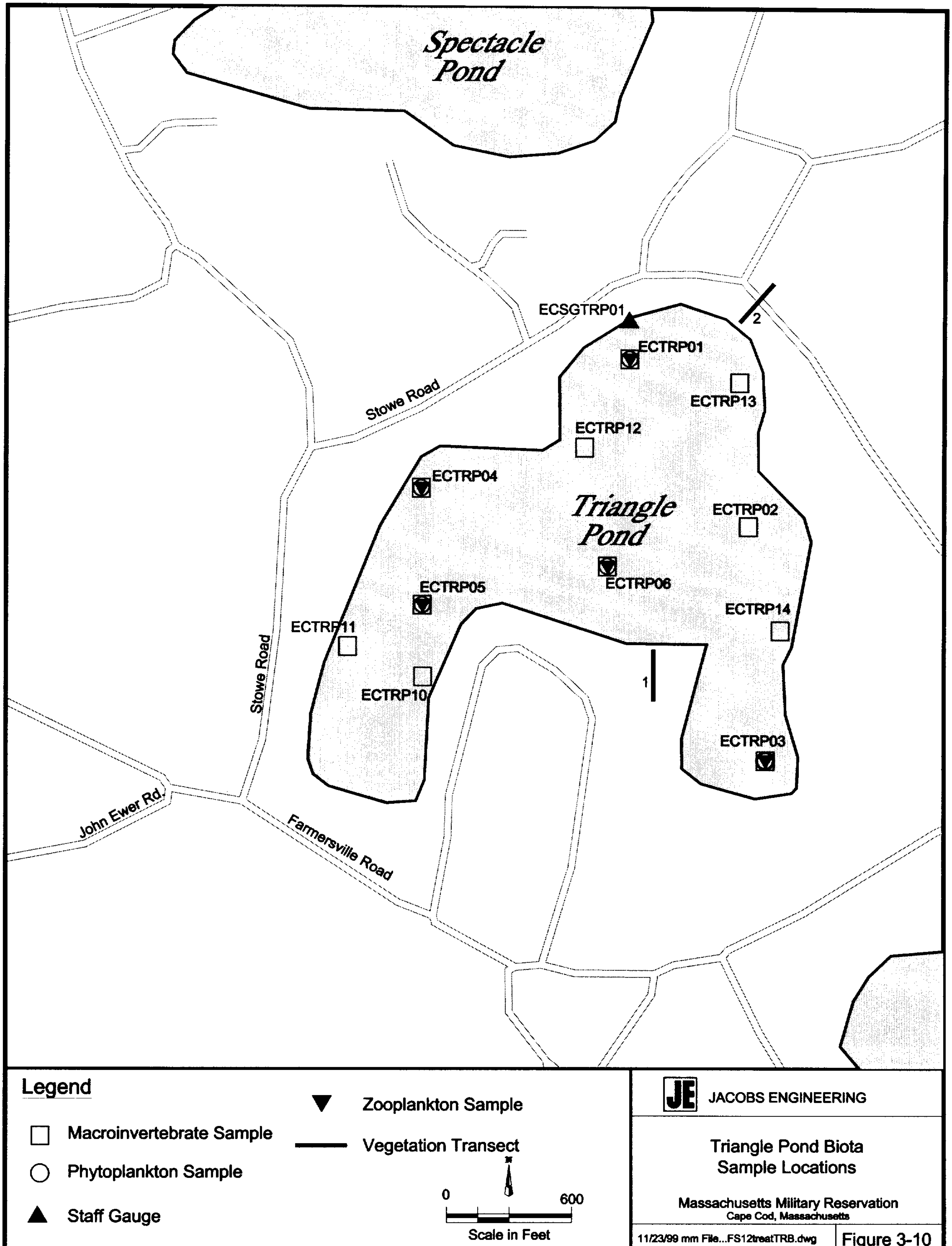
JACOBS ENGINEERING

Peters Pond Biota Sample Locations

Massachusetts Military Reservation
Cape Cod, Massachusetts

11/23/99 mm File...FS12treatPTP.dwg

Figure 3-9



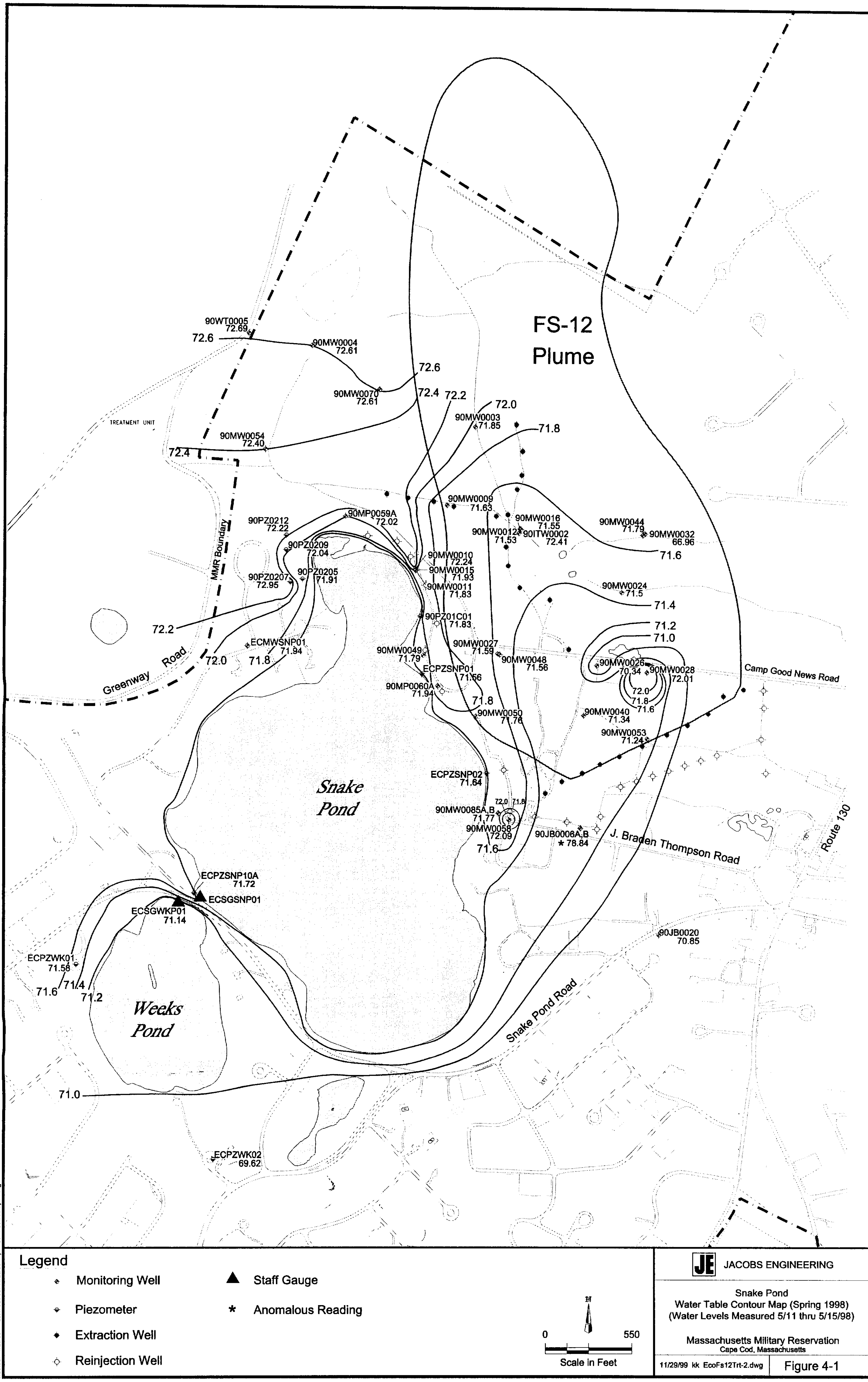
JACOBS ENGINEERING

Triangle Pond Biota Sample Locations

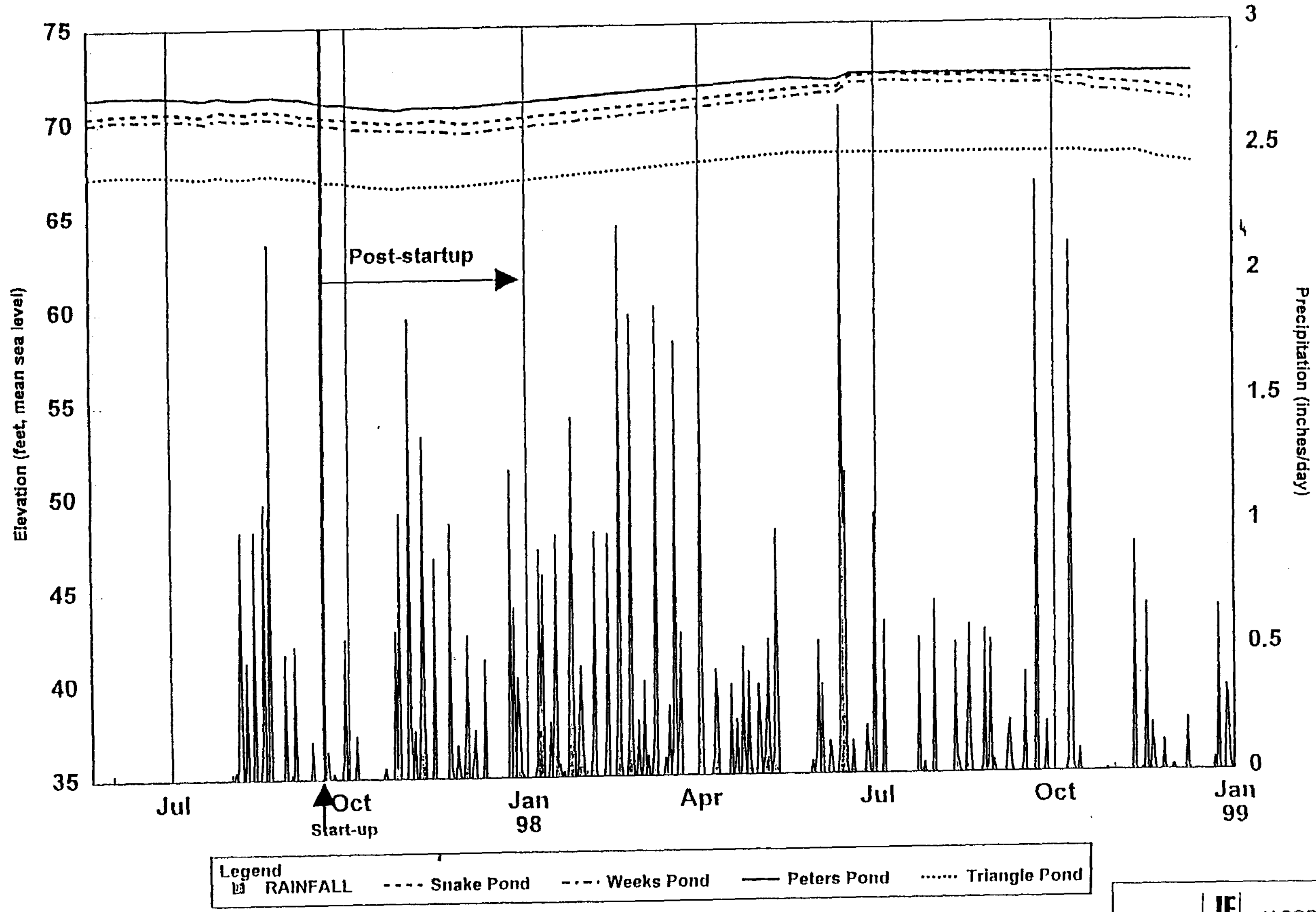
Massachusetts Military Reservation
Cape Cod, Massachusetts

11/23/99 mm File...FS12treatTRB.dwg

Figure 3-10



Q:\Reports\0-REPORTS-99\ECO\FS12treat\SYS\CAD\EcoFS12Trt-2.dwg
created: 11/23/99 last modified: 11/29/99 printed: 12/01/99 by KKing



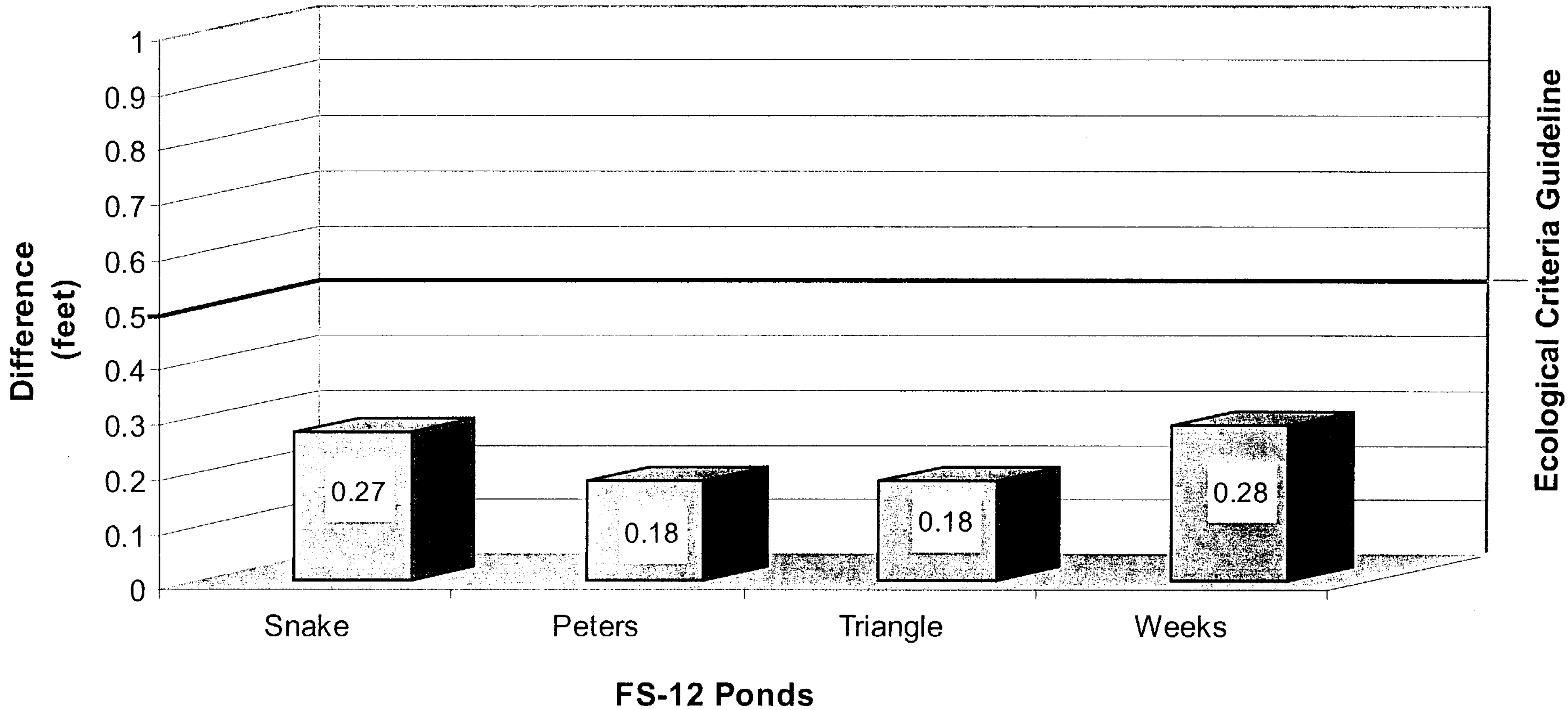
JACOBS ENGINEERING

Pond Surface Elevations for Snake, Peters, Triangle, and Weeks Ponds

Massachusetts Military Reservation
Cape Cod, Massachusetts

11/23/99 pd File:ECO_Cr1-2.cdr

Figure 4-2



Legend

UCL=95% Upper Confidence Level

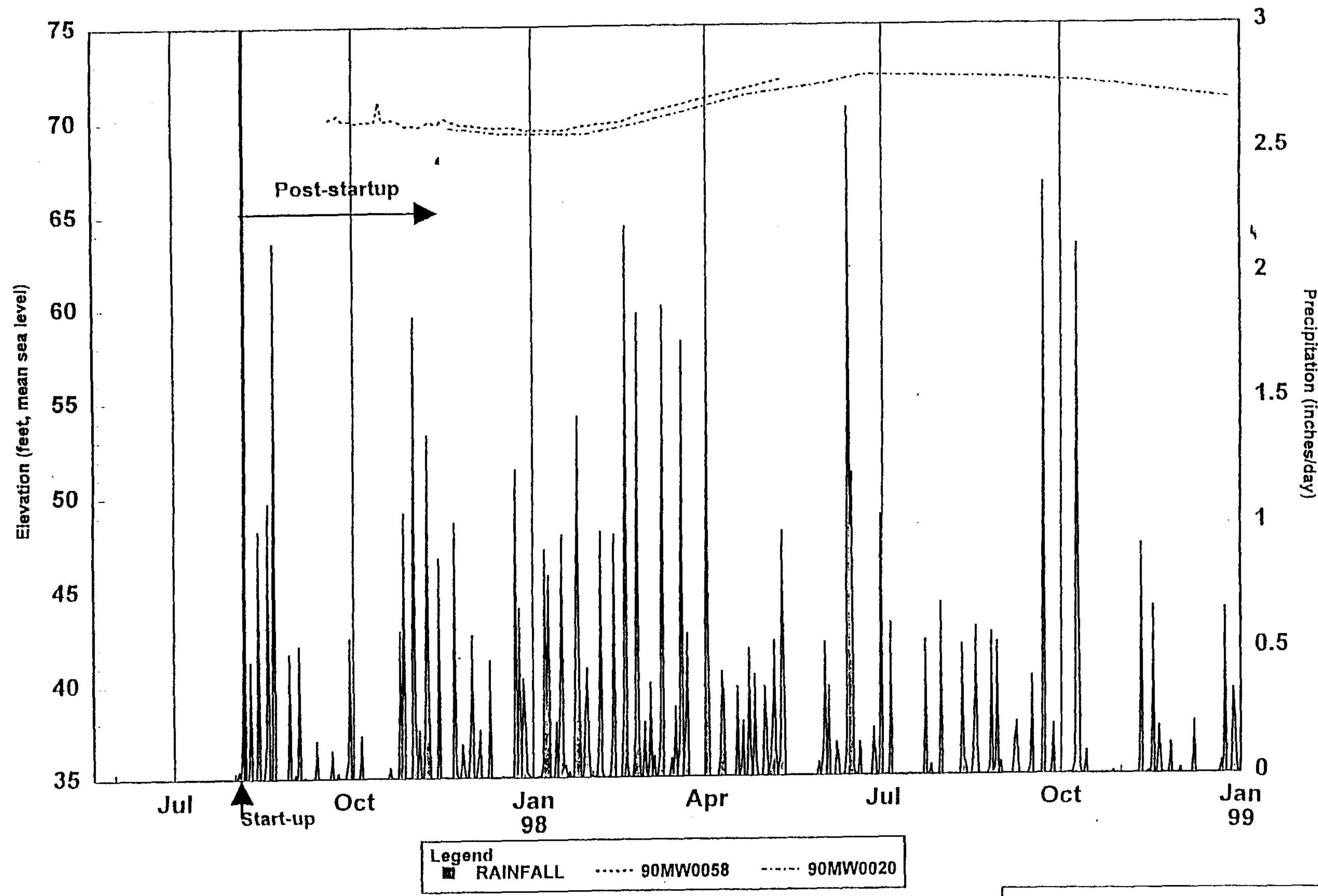
JACOBS ENGINEERING

Difference between Water Level Means and UCL for FS-12 ETR Surface Water Investigation

Massachusetts Military Reservation
Cape Cod, Massachusetts

5/13/99 sr File: Nov_FS-12-1.cdr

Figure 4-3



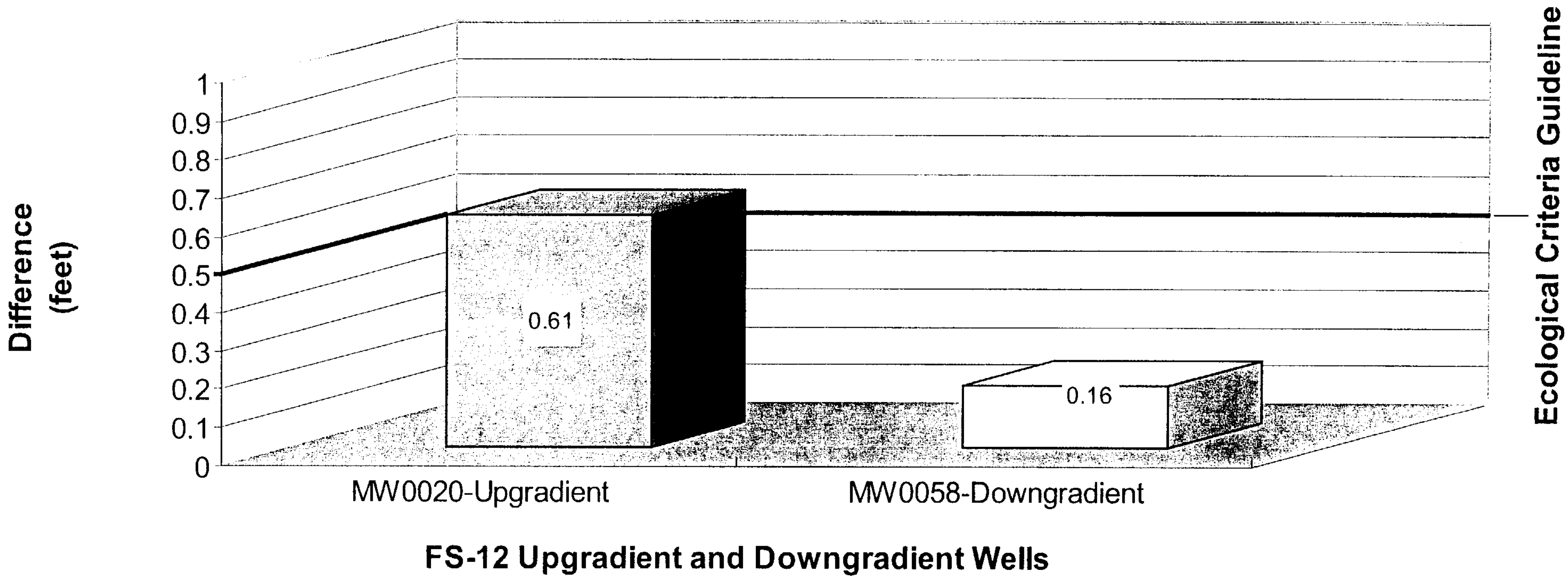
JACOBS ENGINEERING

Groundwater Level Elevations for Upgradient and Downgradient Wells at FS-12

Massachusetts Military Reservation
Cape Cod, Massachusetts

11/23/99 pd File ECO_Crt-2.cdr

Figure 4-4



Legend

UCL=95% Upper Confidence Level

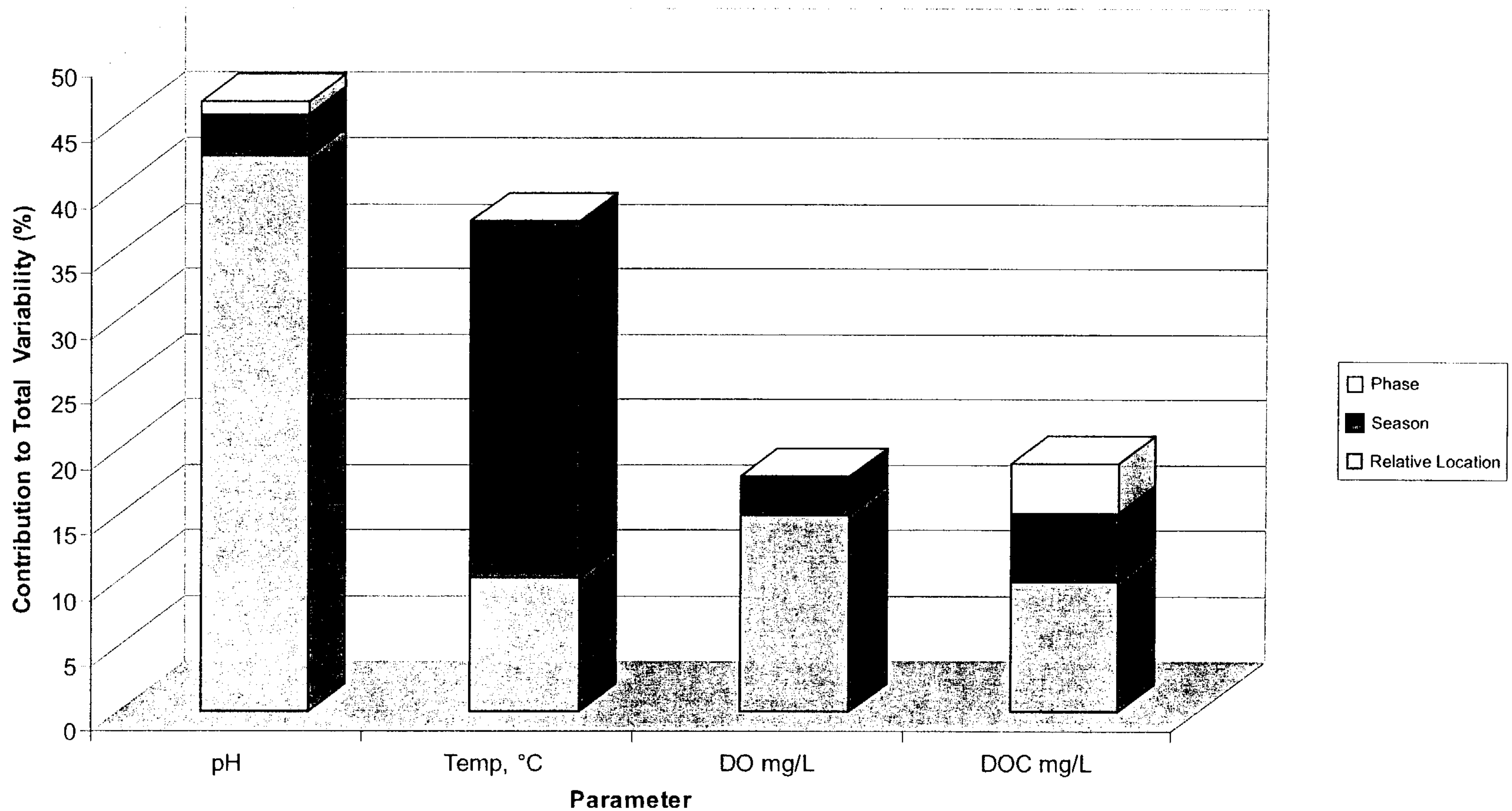
JACOBS ENGINEERING

Difference between Water Level Means and UCL for FS-12 ETR Groundwater Investigation

Massachusetts Military Reservation
Cape Cod, Massachusetts

5/13/99 sr File: Nov_FS-12-2.cdr

Figure 4-5



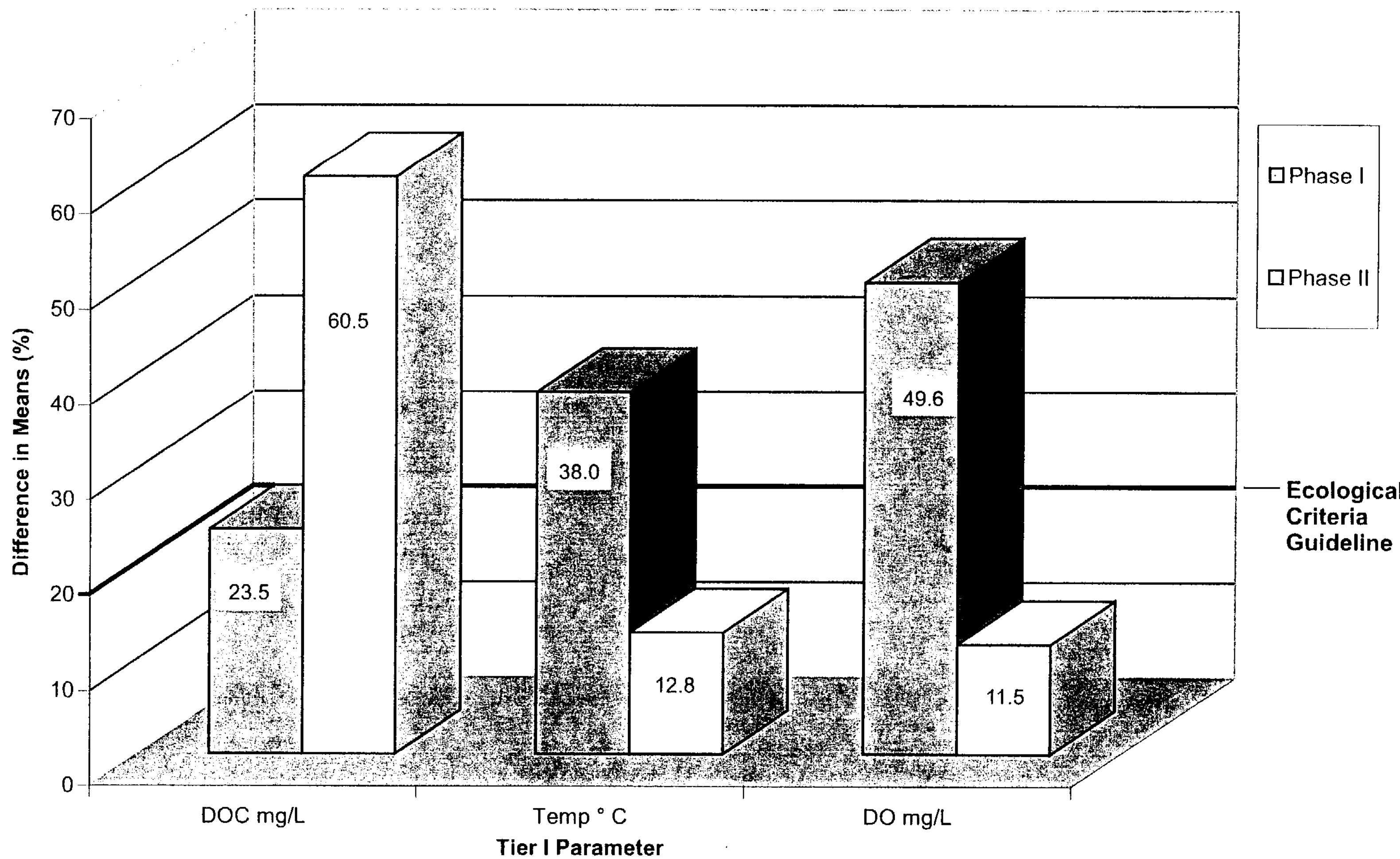
JACOBS ENGINEERING

Total Variability Explained by Model
FS-12 Groundwater Tier I Parameters
(Sum of Squares %)

Massachusetts Military Reservation
Cape Cod, Massachusetts

5/13/99 sr File: Nov_FS-12-3.cdr

Figure 4-6



Legend

°C=degrees Celsius
DO=Dissolved Oxygen
DOC=Dissolved Organic Carbon
mg/L=milligrams per liter

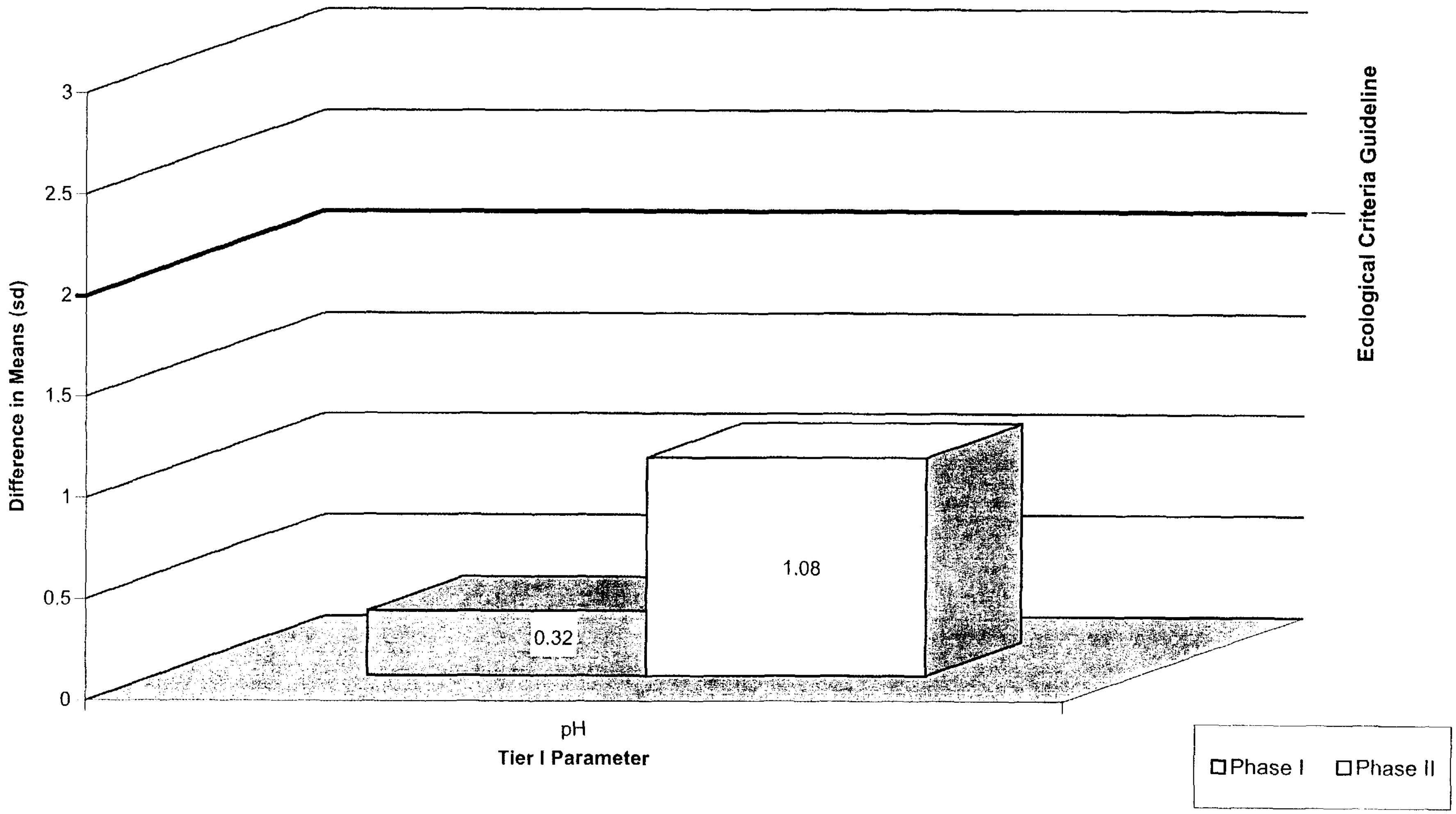
JACOBS ENGINEERING

FS-12 Groundwater Tier I Parameters Phase I and Phase II Difference in Means

Massachusetts Military Reservation
Cape Cod, Massachusetts

5/13/99 sr File: Nov_FS-12-4.cdr

Figure 4-7



Legend

sd=standard deviation

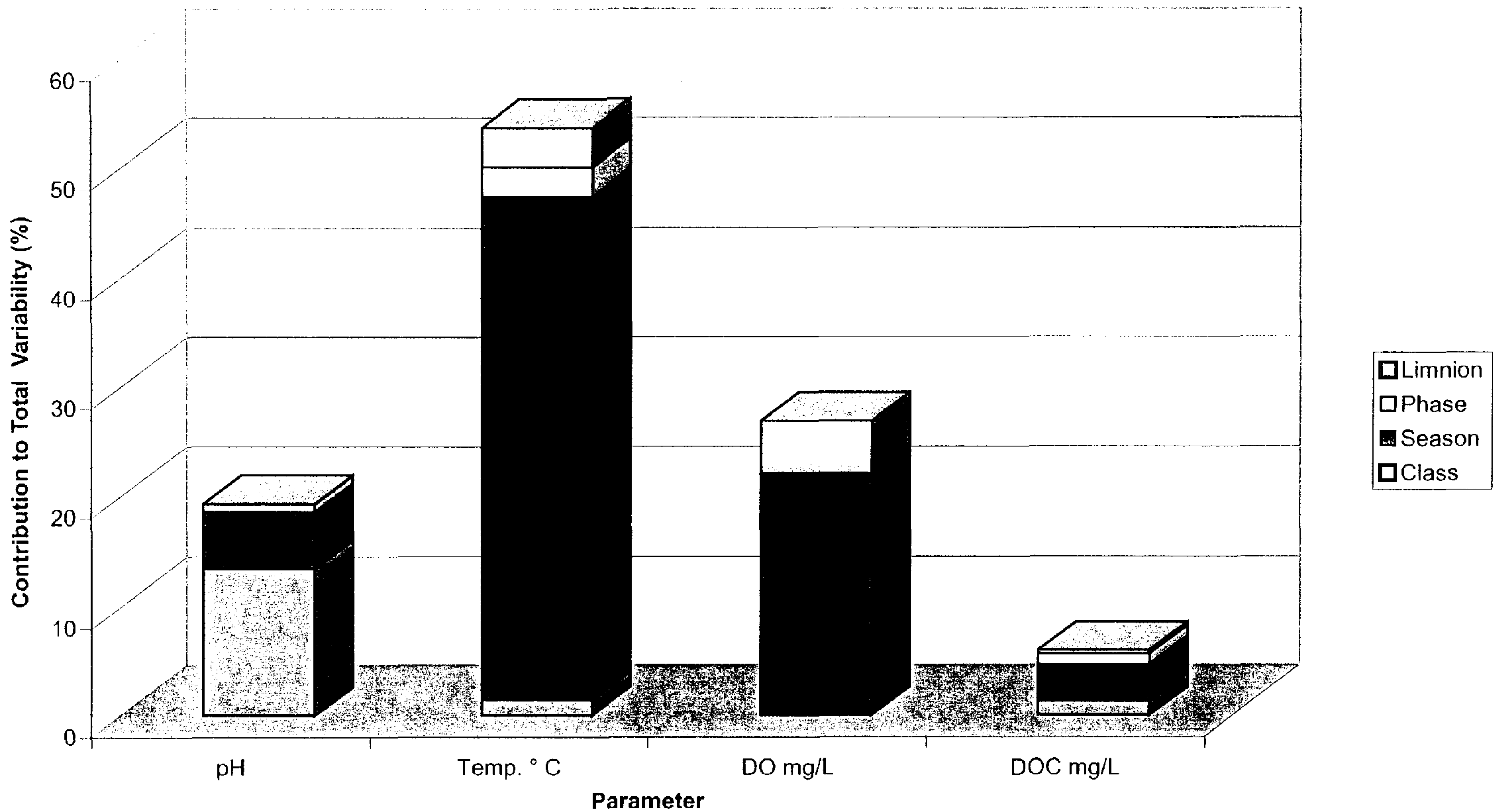
JACOBS ENGINEERING

FS-12 Groundwater Tier I Parameters Phase I and Phase II Difference in Means

Massachusetts Military Reservation
Cape Cod, Massachusetts

5/13/99 sr File: Nov_FS-12-5.cdr

Figure 4-8



Legend

°C=degrees Celsius
DO=Dissolved Oxygen
DOC=Dissolved Organic Carbon
mg/L=milligrams per liter

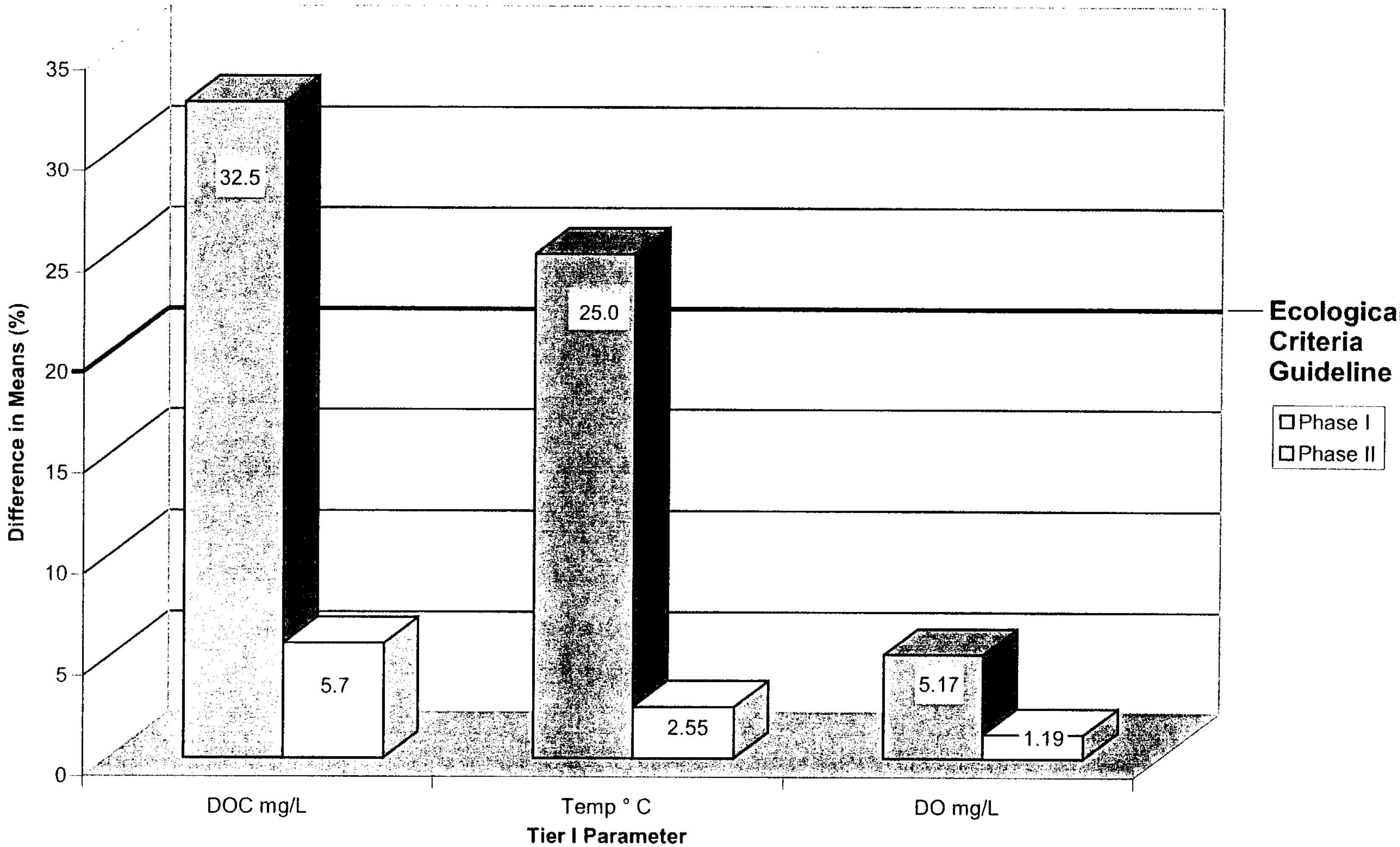
JE JACOBS ENGINEERING

Total Variability Explained by Model
FS-12 Surface Water Tire I Parameters
(Sum of Squares %)

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/5/99 sr File: Nov_FS-12-6.cdr

Figure 4-9



Legend

°C=degrees Celsius
DO=Dissolved Oxygen
DOC=Dissolved Organic Carbon
mg/L=milligrams per liter

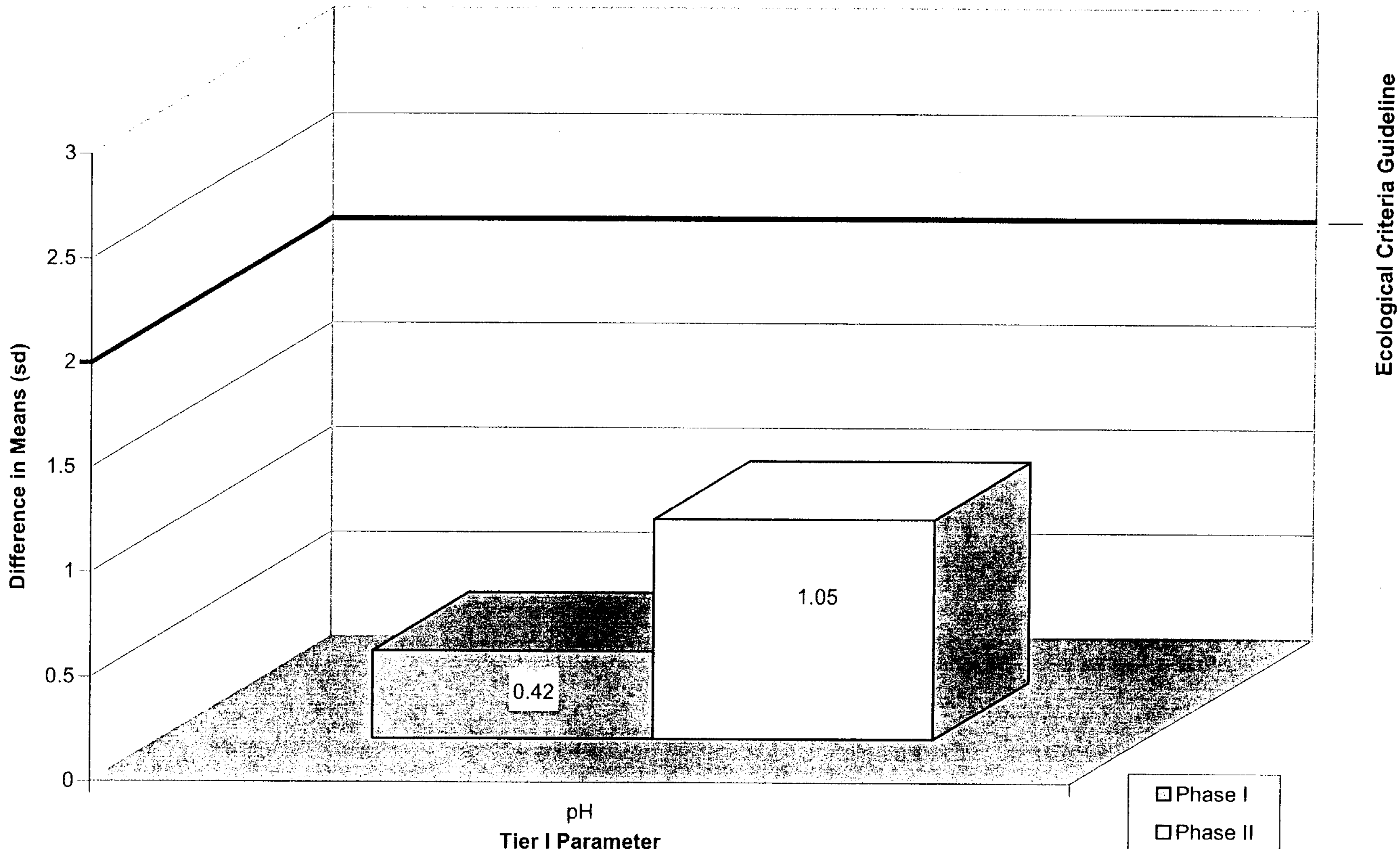
JACOBS ENGINEERING

FS-12 Surface Water Tier I Parameters Phase I and Phase II Difference in Means

Massachusetts Military Reservation
Cape Cod, Massachusetts

5/13/99 sr File: Nov_FS-12-7.cdr

Figure 4-10



Legend

sd=standard deviation

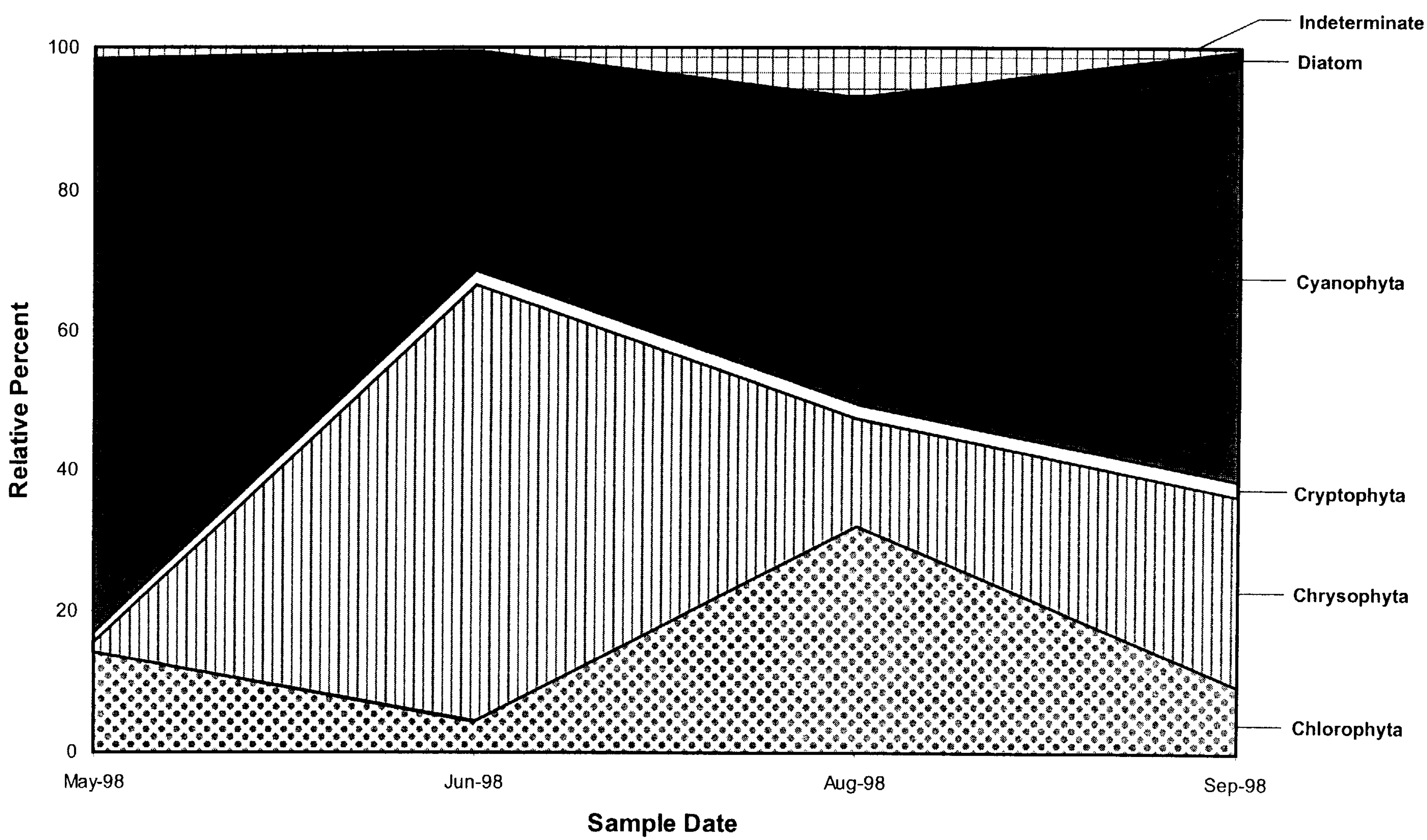
JACOBS ENGINEERING

FS-12 Surface Water Tier I Parameters Phase I and Phase II Difference in Means

Massachusetts Military Reservation
Cape Cod, Massachusetts

5/13/99 sr File: Nov_FS-12-8.cdr

Figure 4-11

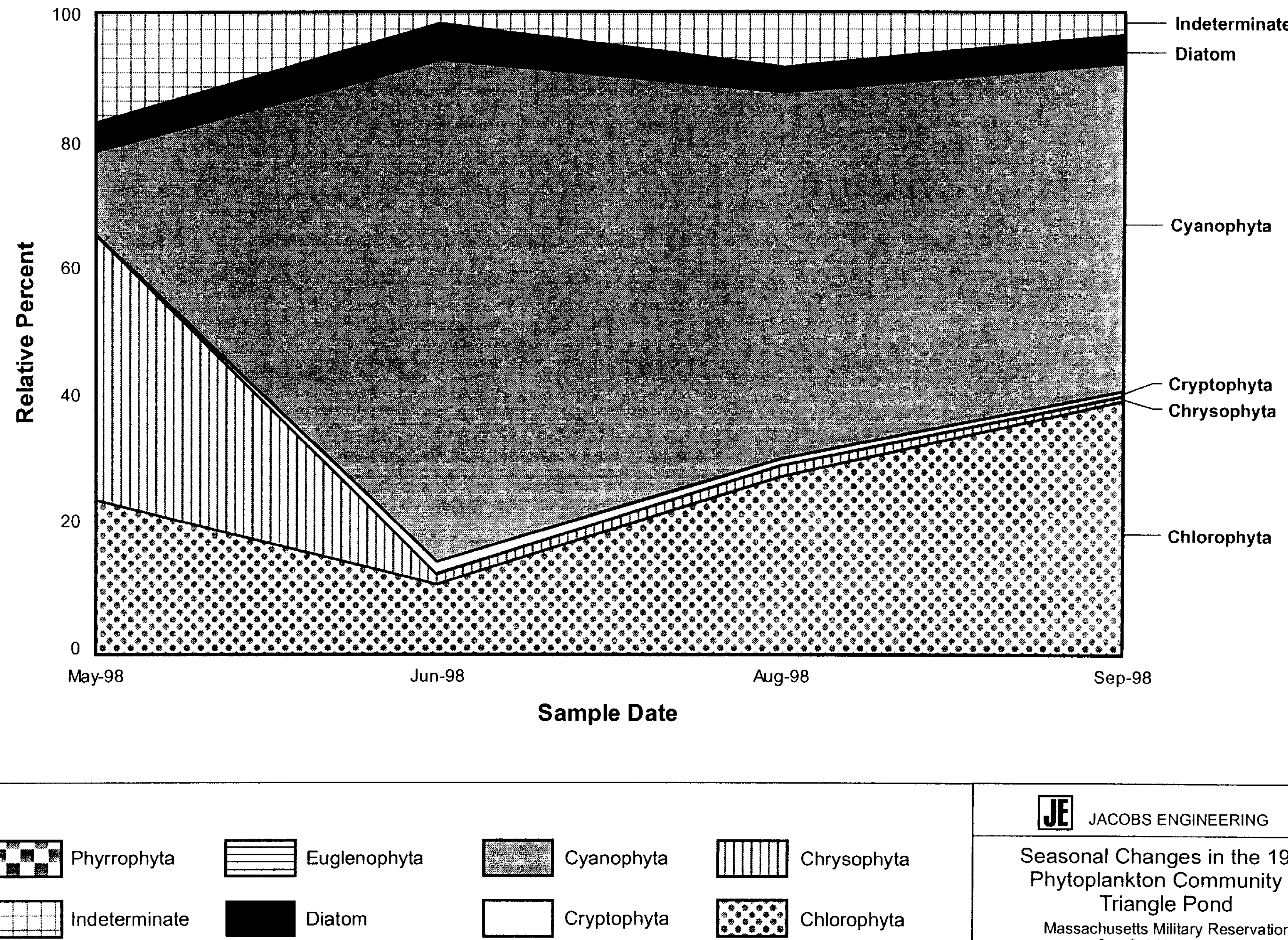


JACOBS ENGINEERING

Seasonal Changes in the 1998 Phytoplankton Community in Snake Pond

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/8/99 sr File: fs12_phyto-1.cdr | Figure 4-12



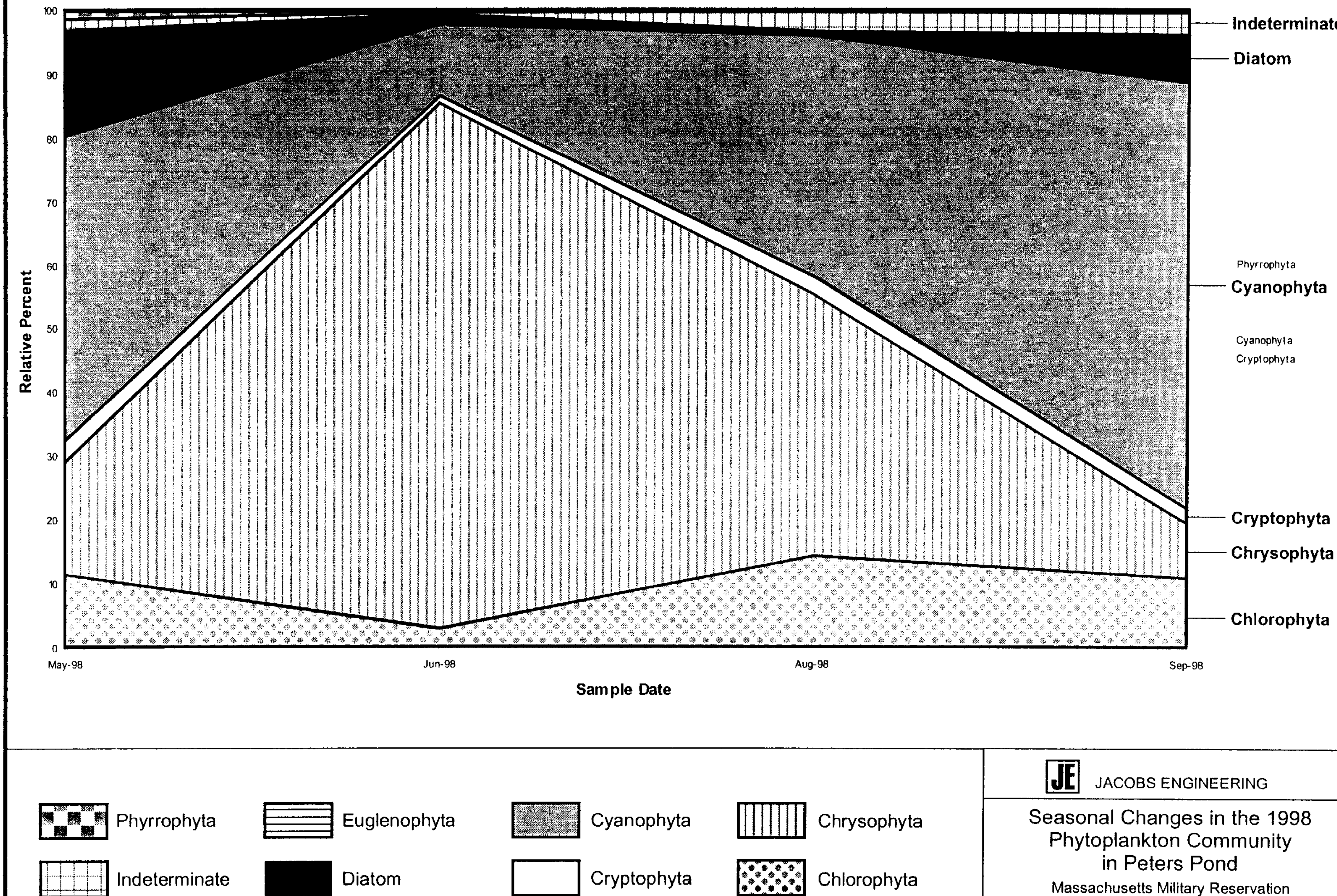
JACOBS ENGINEERING

Seasonal Changes in the 1998 Phytoplankton Community in Triangle Pond

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/8/99 sr File: fs12_phyto-2.cdr

Figure 4-13



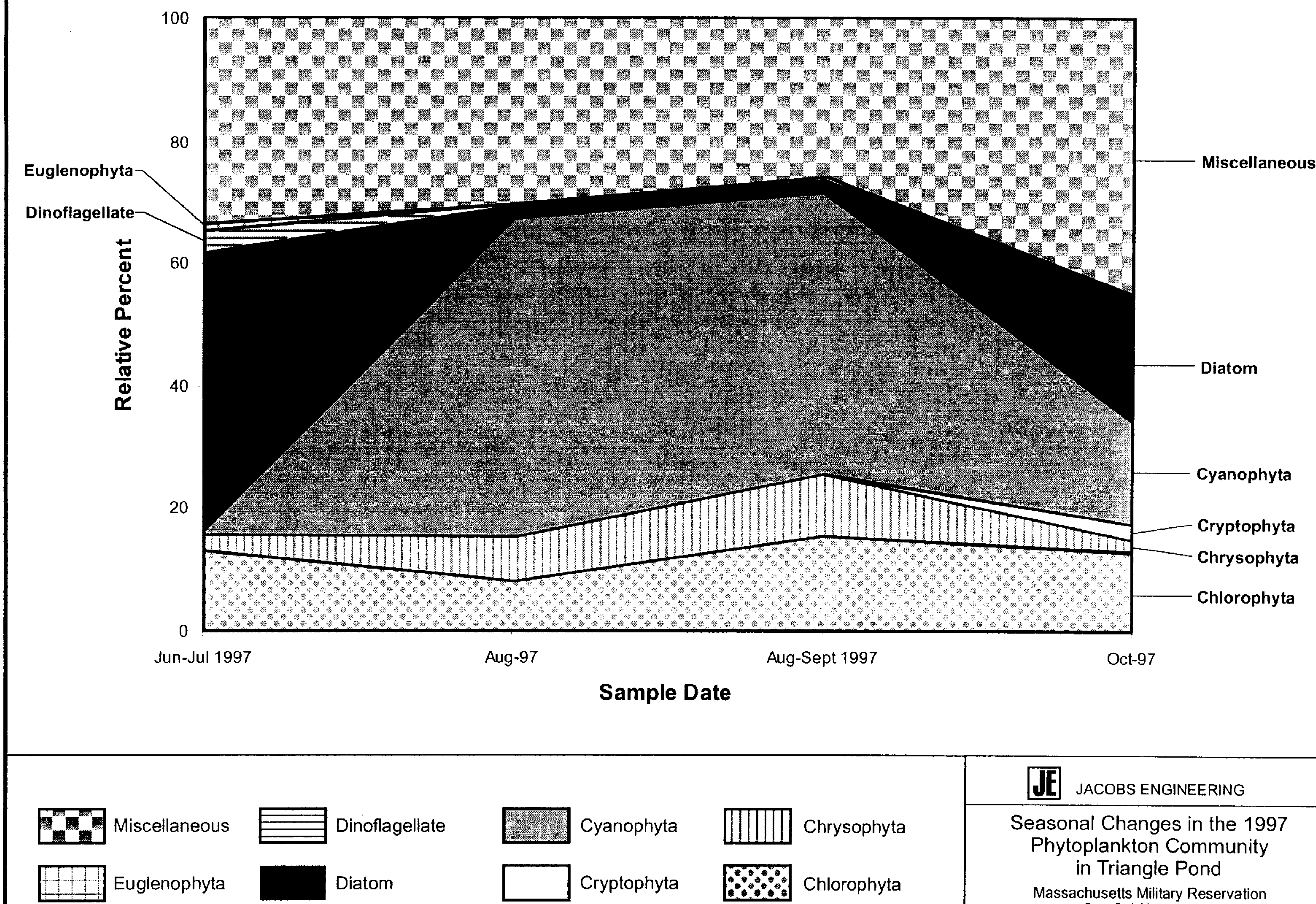
JACOBS ENGINEERING

Seasonal Changes in the 1998 Phytoplankton Community in Peters Pond

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/8/99 sr File: fs12_phyto-3.cdr

Figure 4-14

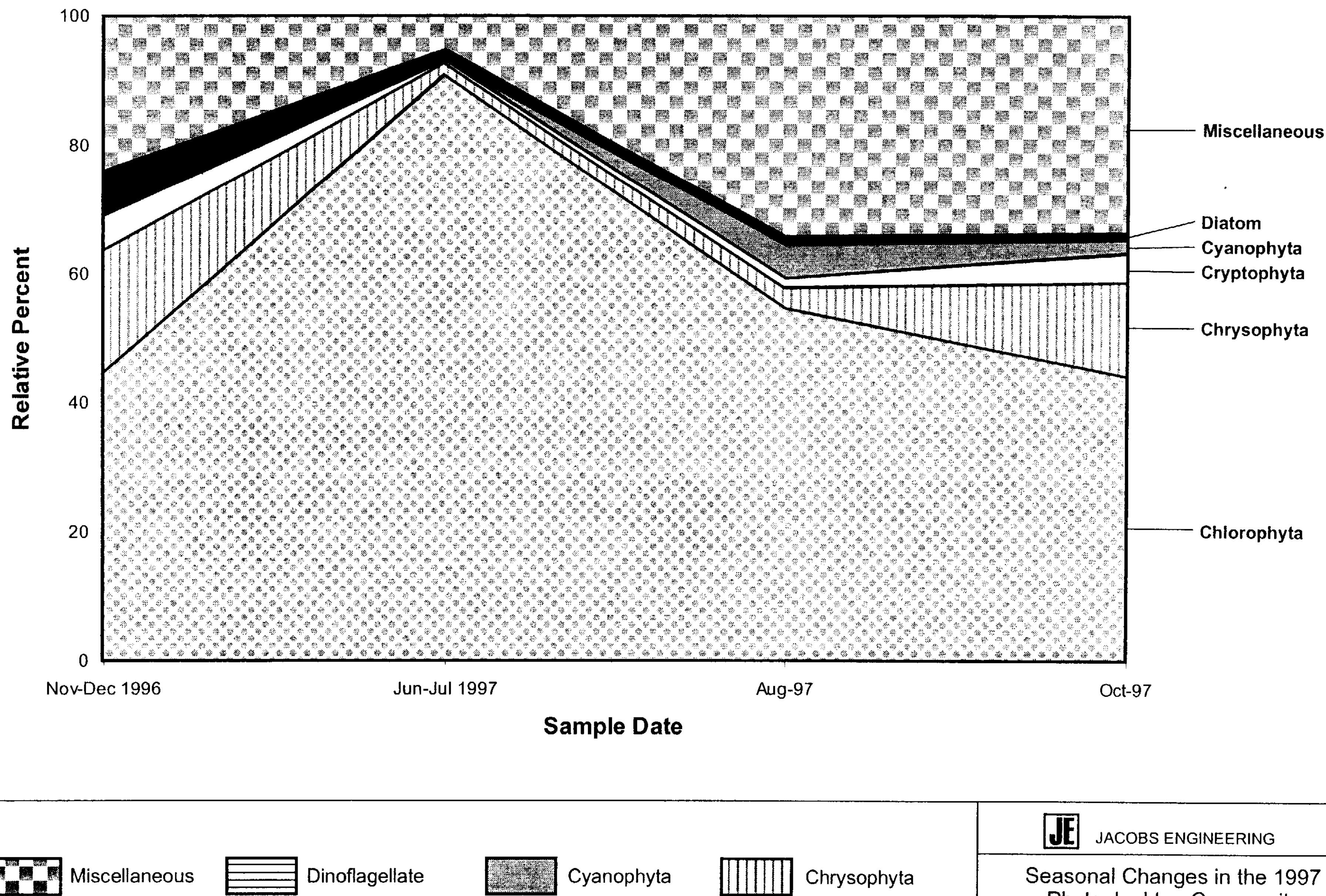


JACOBS ENGINEERING

Seasonal Changes in the 1997 Phytoplankton Community in Triangle Pond

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/8/99 sr File: fs12_phyto-4.cdr | Figure 4-15



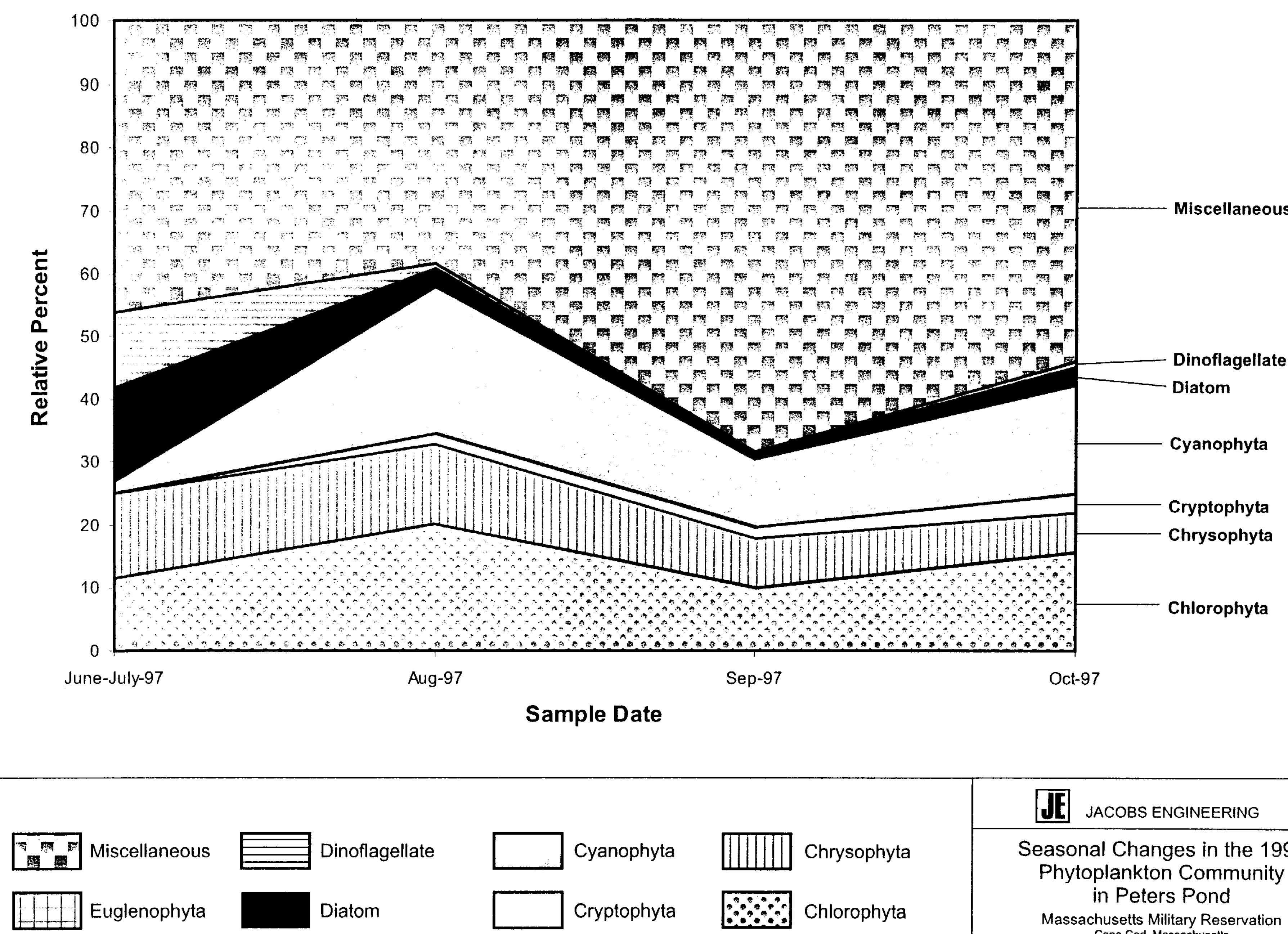
JACOBS ENGINEERING

Seasonal Changes in the 1997 Phytoplankton Community in Snake Pond

Massachusetts Military Reservation
Cape Cod, Massachusetts

5/13/99 sr File: fs12_phyto-5.cdr

Figure 4-16



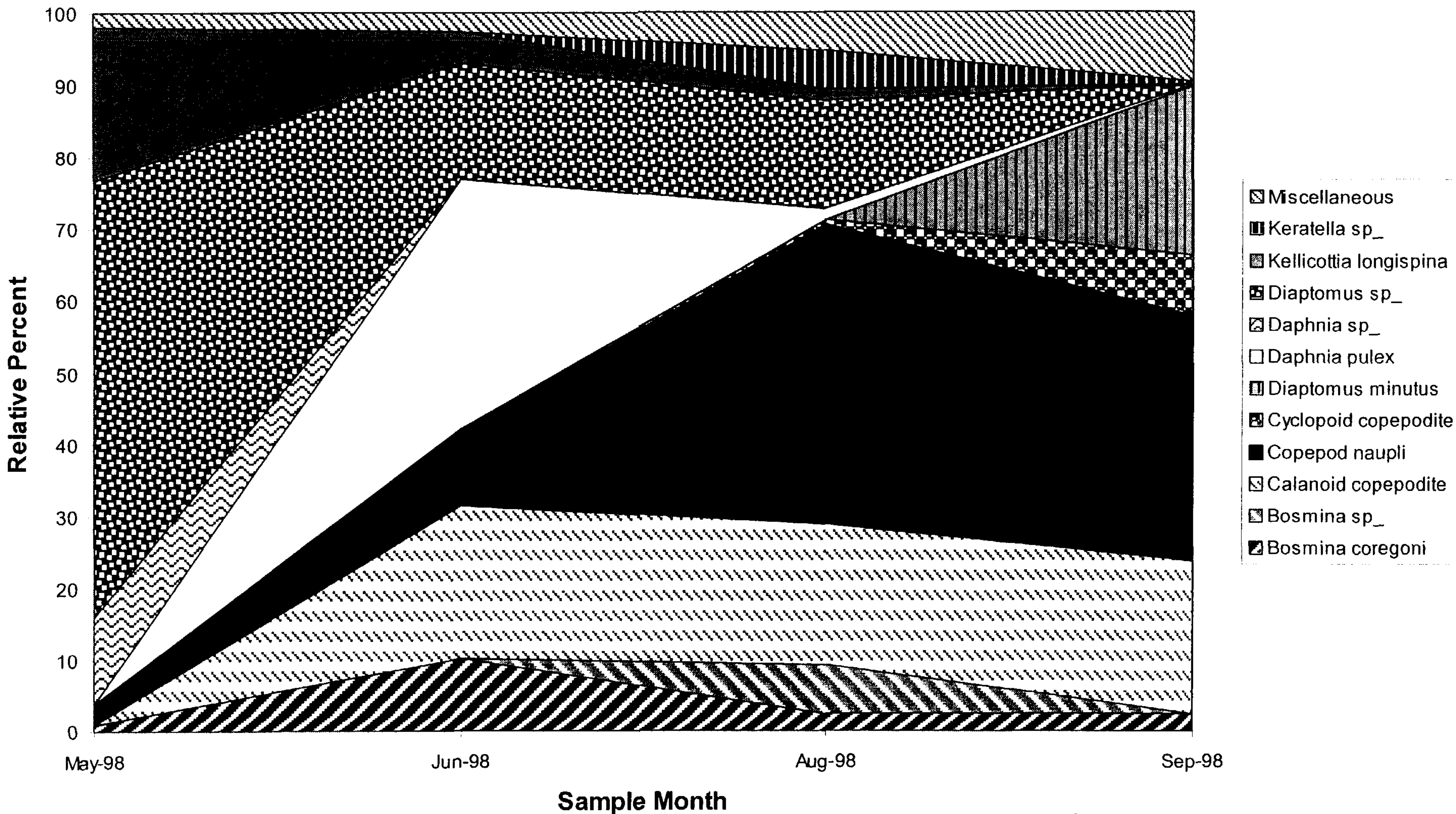
JACOBS ENGINEERING

Seasonal Changes in the 1997 Phytoplankton Community in Peters Pond

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/8/99 sr File: fs12_phyto-6.cdr

Figure 4-17



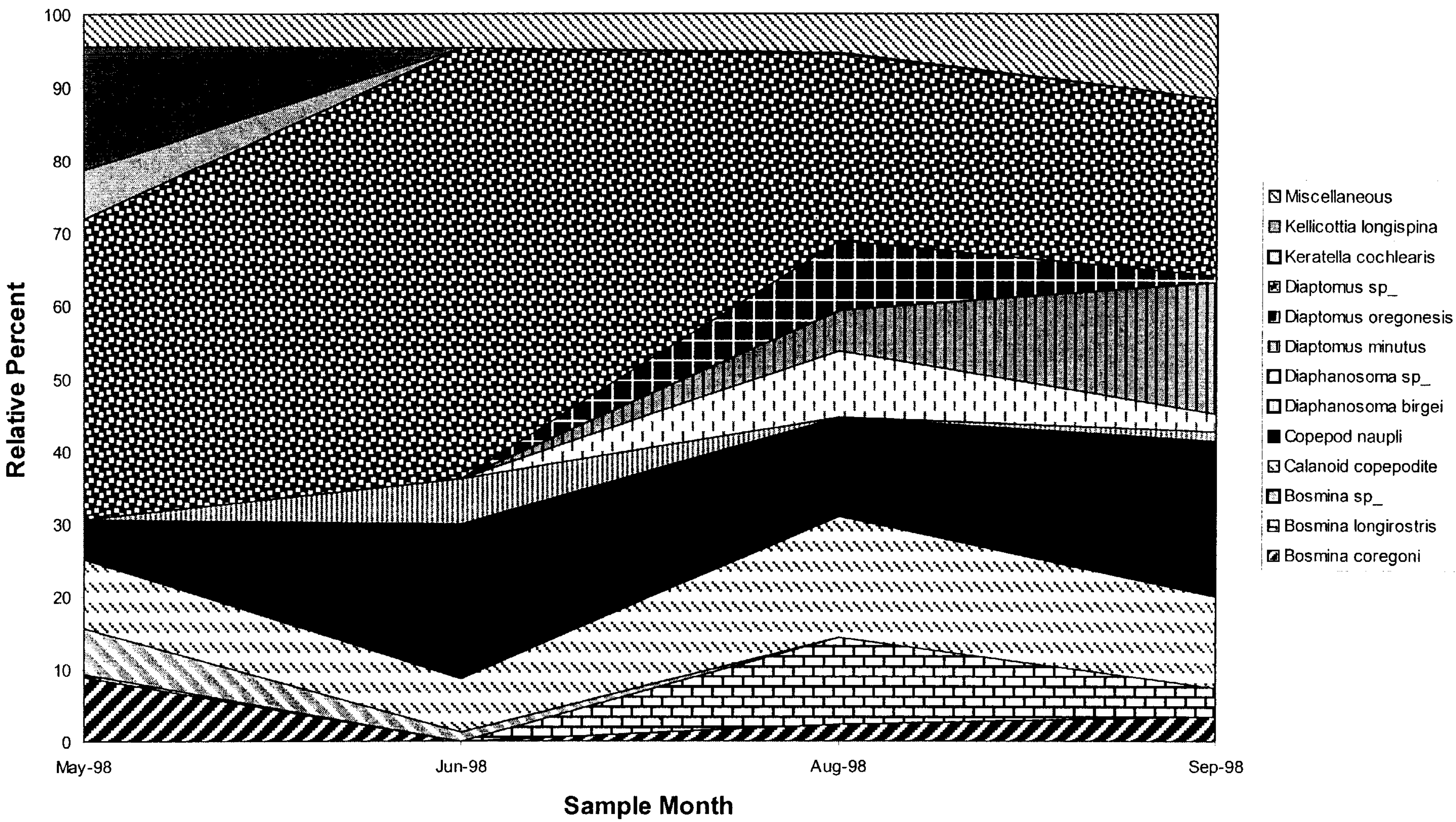
JACOBS ENGINEERING

Relative Abundance of Zooplankton Genera in Snake Pond 1998

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/12/99 sr File: fs12_zoo-1.cdr

Figure 4-18



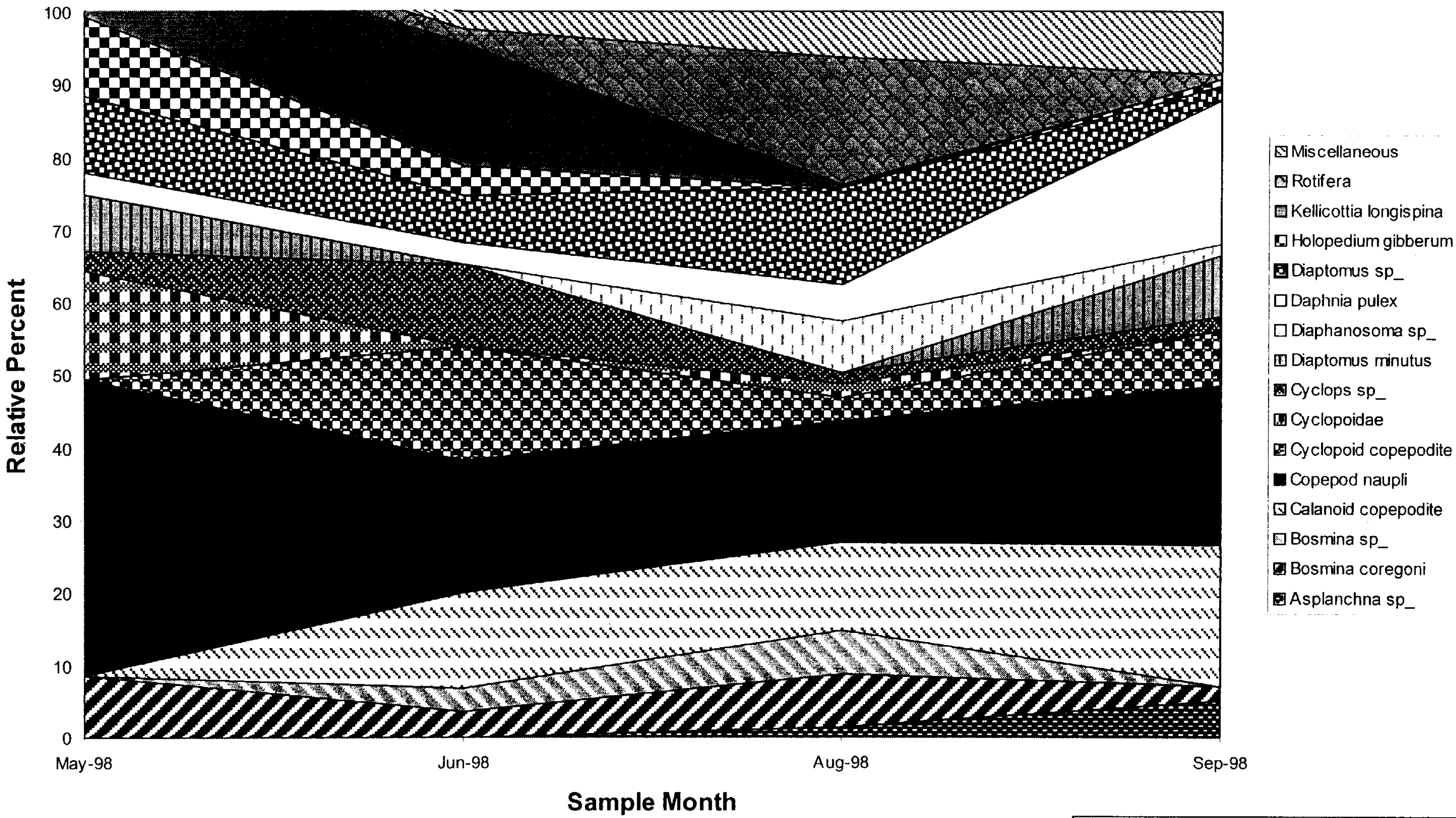
JACOBS ENGINEERING

Relative Abundance of Zooplankton Genera in Triangle Pond 1998

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/12/99 sr File: fs12_zoo-2.cdr

Figure 4-19

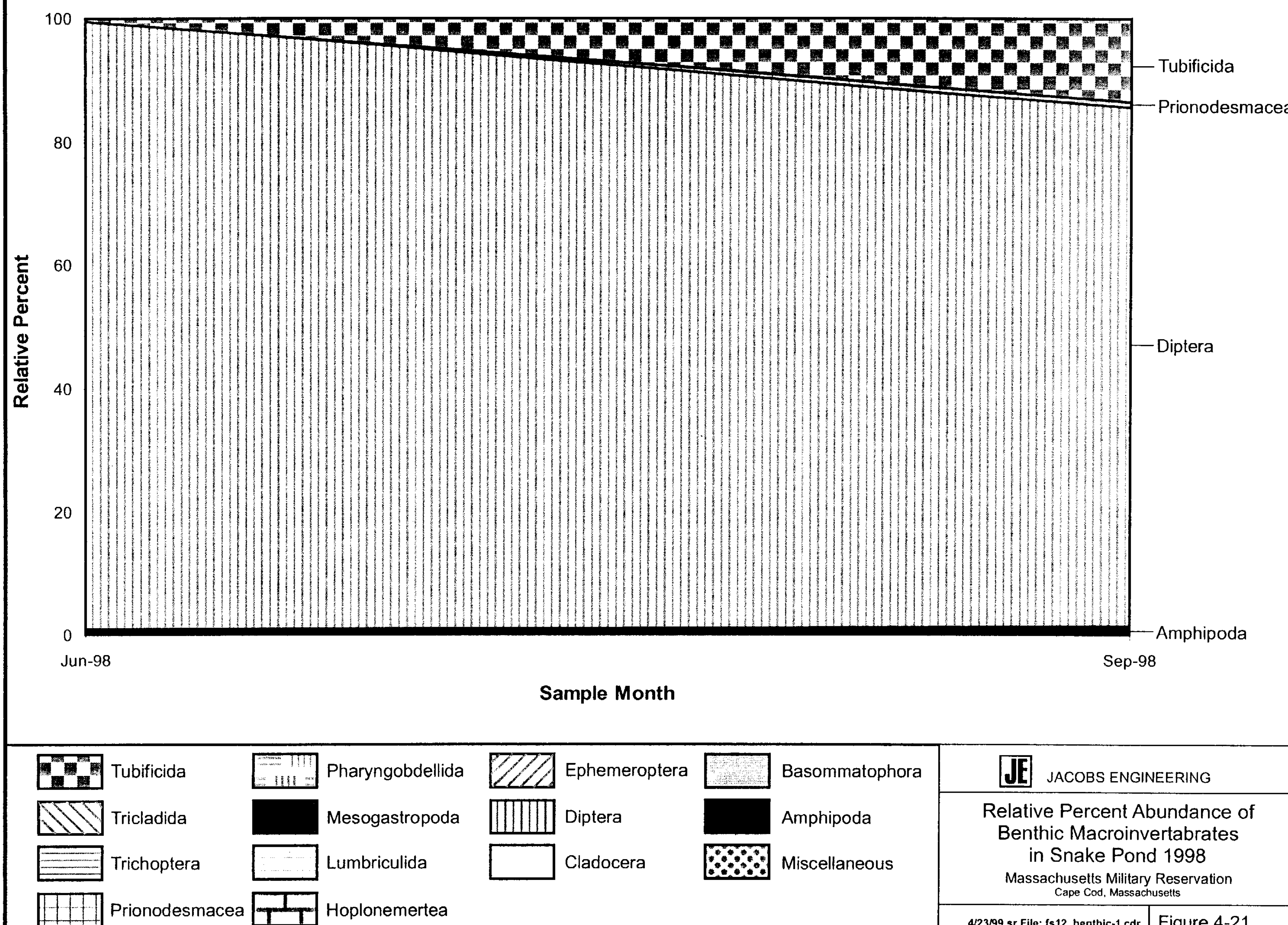


JACOBS ENGINEERING

Relative Abundance of Zooplankton Genera in Peters Pond 1998

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/12/99 sr File: fs12_zoo-3.cdr | Figure 4-20



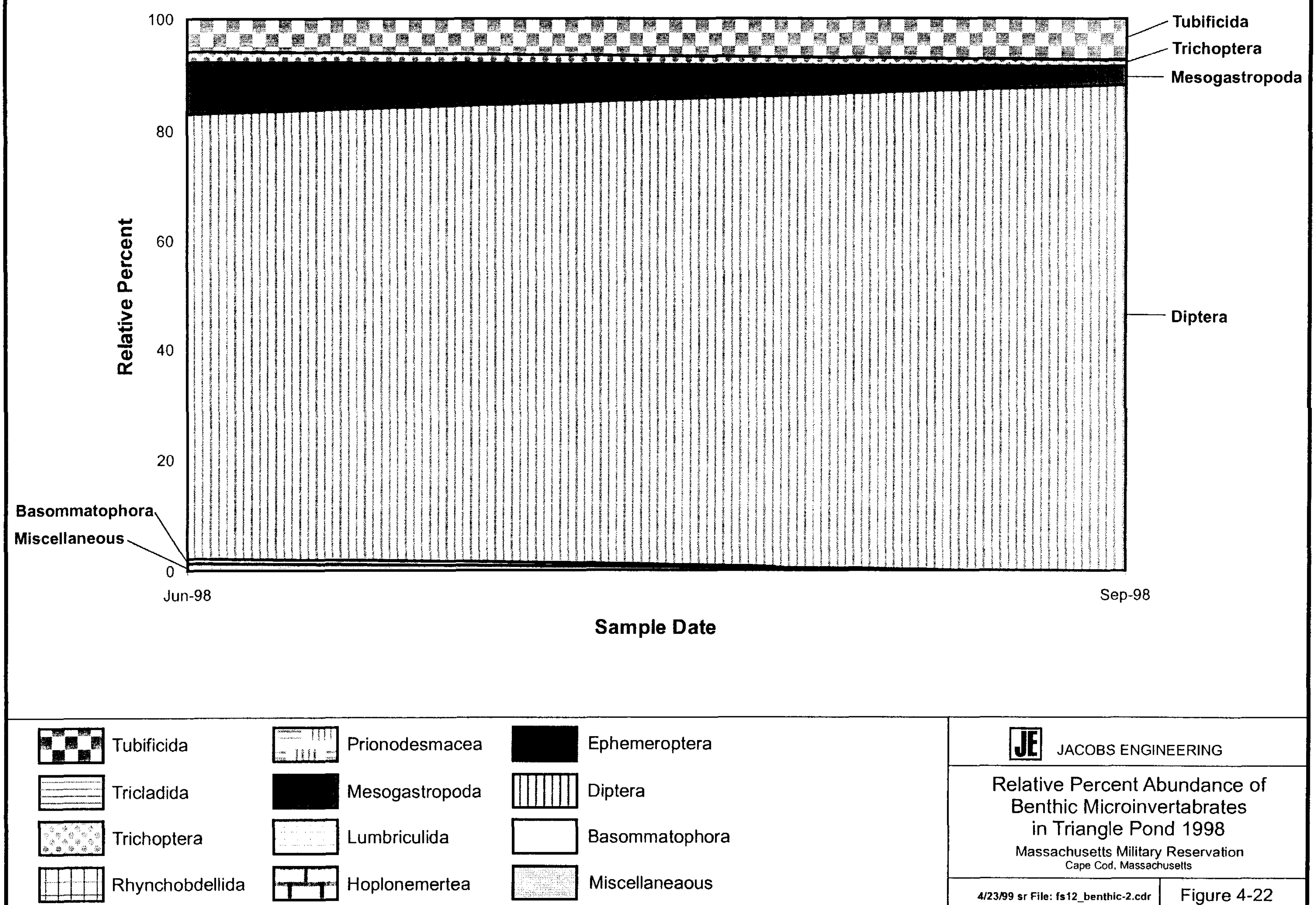
JACOBS ENGINEERING

Relative Percent Abundance of Benthic Macroinvertabrates in Snake Pond 1998

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/23/99 sr File: fs12_benthic-1.cdr

Figure 4-21



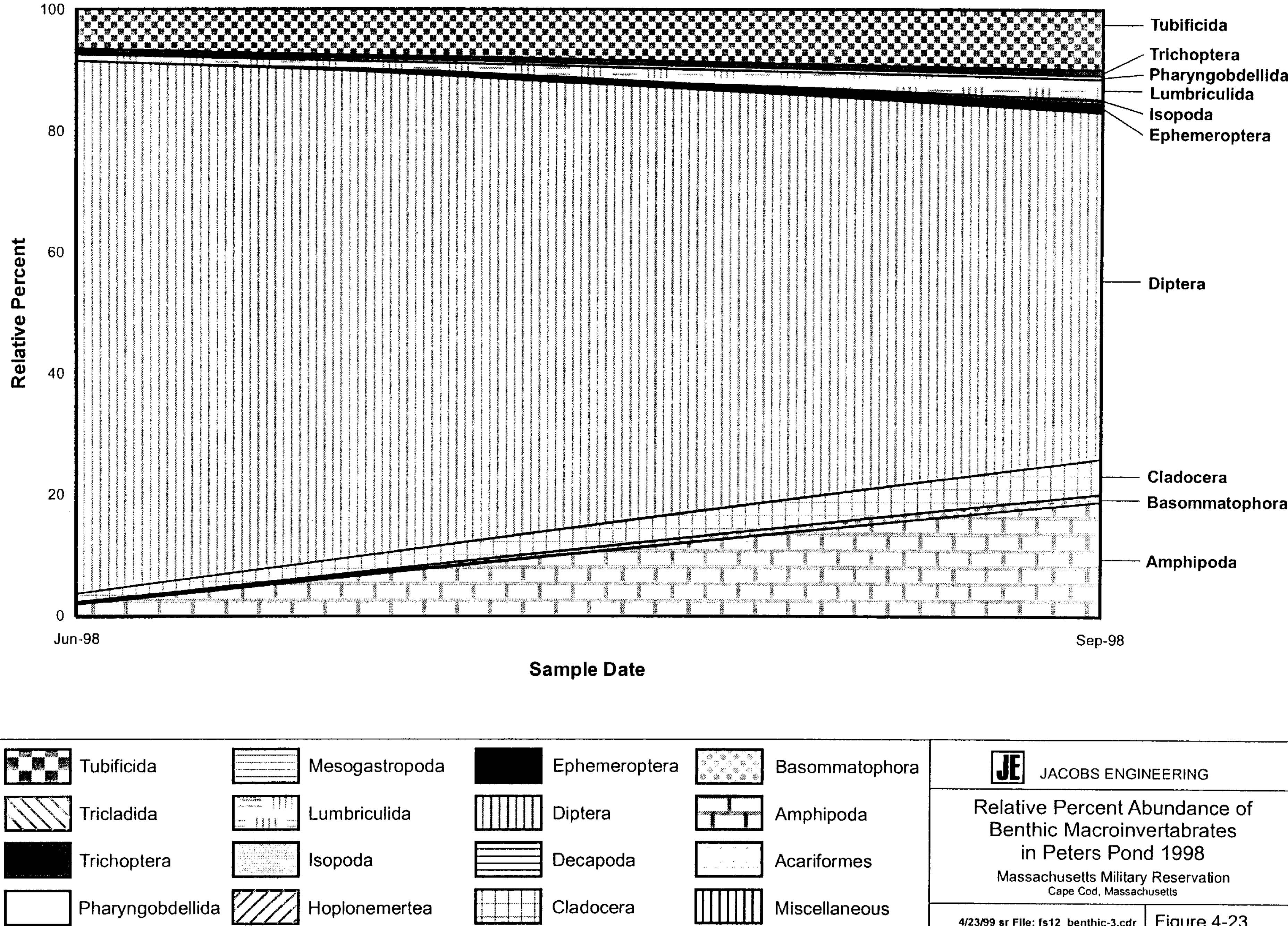
JACOBS ENGINEERING

Relative Percent Abundance of Benthic Microinvertabrates in Triangle Pond 1998

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/23/99 sr File: fs12_benthic-2.cdr

Figure 4-22

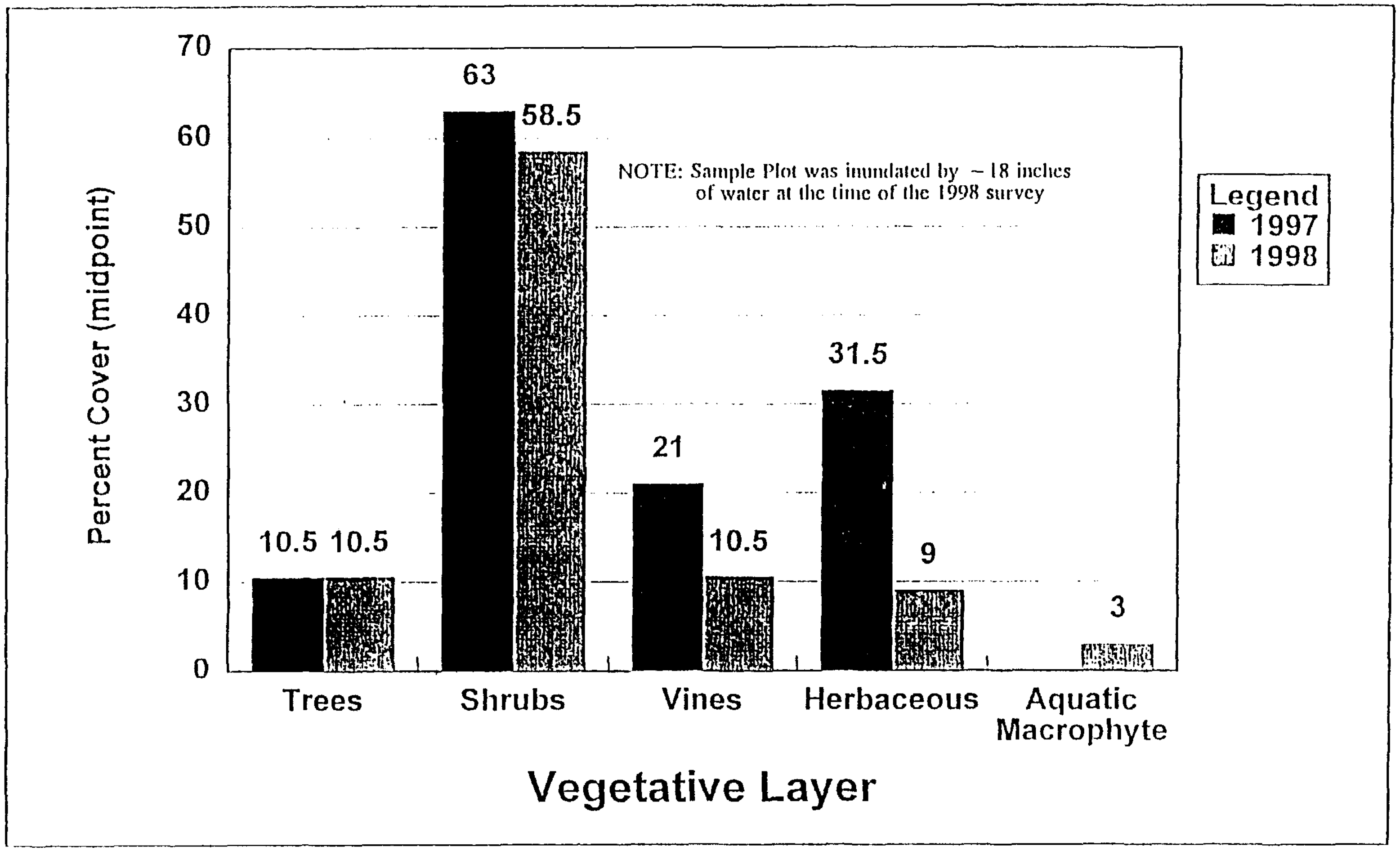


JACOBS ENGINEERING

Relative Percent Abundance of Benthic Macroinvertabrates in Peters Pond 1998

Massachusetts Military Reservation
Cape Cod, Massachusetts

4/23/99 sr File: fs12_benthic-3.cdr | Figure 4-23



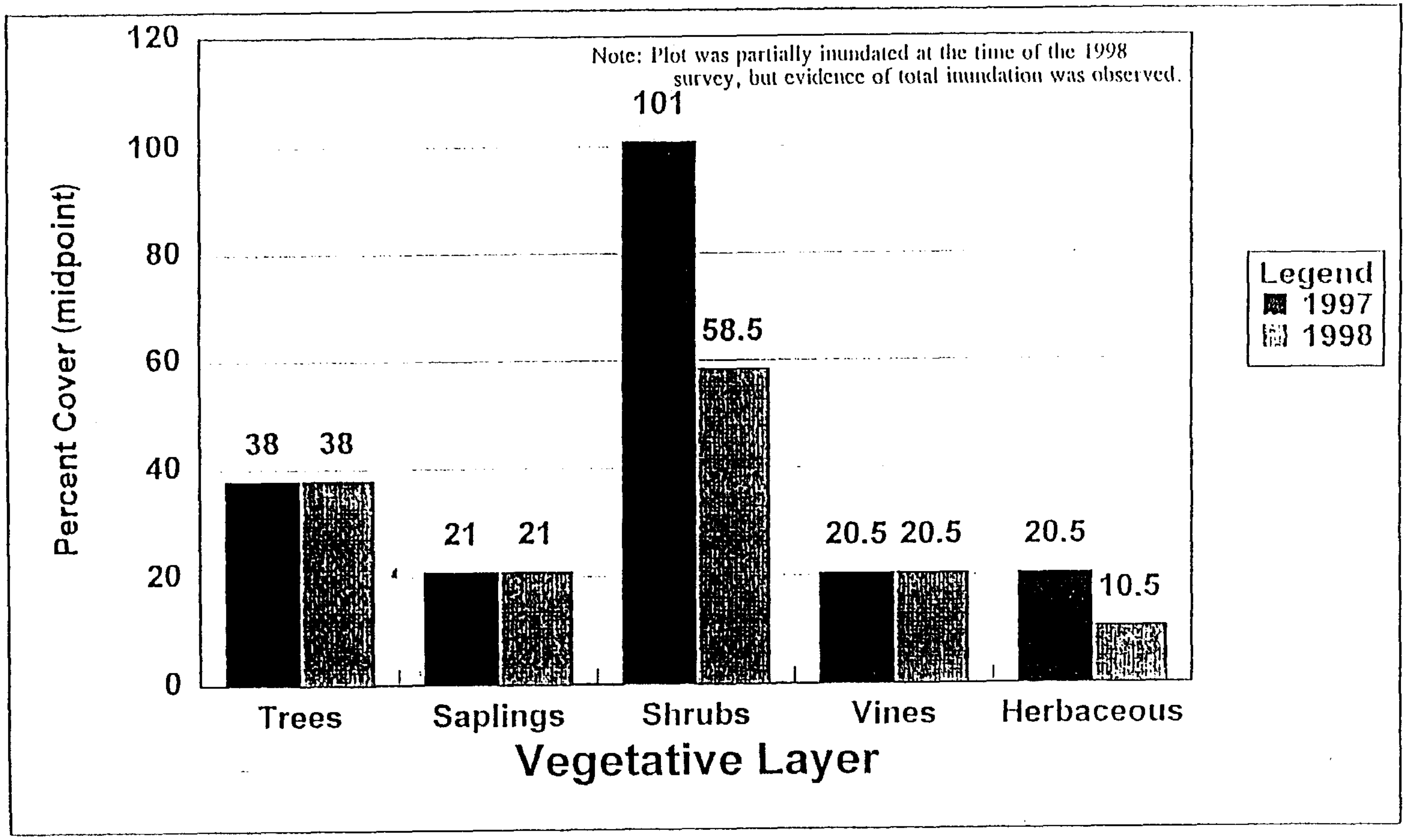
JACOBS ENGINEERING

Snake Pond--Sandwich, MA
Transect #3, Plot B

Massachusetts Military Reservation
Cape Cod, Massachusetts

11/23/99 pd File:ECO_Crt-2.cdr

Figure 4-24



JACOBS ENGINEERING

Triangle Pond--Sandwich, MA
Transect #1, Plot B

Massachusetts Military Reservation
Cape Cod, Massachusetts

11/23/99 pd File:ECO_Crt-2.cdr

Figure 4-25

TABLES

Table 3-1
Monthly Groundwater Sample Locations for FS-12 Phase II

Habitat	Location Identifier	Well Type	Rationale for Selecting Sample Location	Number of Samples	Parameters
Snake Pond (Study Area)	90MW0004	Monitoring well	Monitor ambient upgradient groundwater quality	1	Physicochemical
	90PZ0205	Piezometer	Monitor ambient upgradient groundwater quality	1	Physicochemical
	90MW0020	Monitoring well	Monitor in plume groundwater quality	1	Physicochemical
	90RIW0006	Reinjection well	Monitor reinjection water quality	1	Physicochemical
	90RIW0014	Reinjection well	Monitor reinjection water quality	1	Physicochemical
	90RIW0028	Reinjection well	Monitor reinjection water quality	1	Physicochemical

Table 3-2
Water Level Staff Gauge Locations for FS-12 Phase II Monitoring

Habitat	Location Identifier	Well Type	Rationale for Selecting Sample Location	Number of Samples	Parameters
Snake Pond (Study Area)	ECSGSNP01	Staff Gauge	Measure surface water elevation in study pond	1	Water levels
Weeks Pond (Study Area)	ECSGWKP01	Staff Gauge	Measure surface water elevation in study pond	1	Water levels
Peters Pond (Reference Area)	ECSGPTP01	Staff Gauge	Measure surface water elevation in reference pond	1	Water levels
Triangle Pond (Reference Area)	ECSGTRP01	Staff Gauge	Measure surface water elevation in reference pond	1	Water levels

Table 3-3
Quarterly Groundwater Sample Locations for
FS-12 Phase II

Habitat	Location Identifier	Well Type	Rationale for Selecting Sample Location	Number of Samples	Parameters
Snake Pond (Study Area)	90PZ0205	Monitoring well	Monitor background water quality	1	Physicochemical
	90MW0004	Monitoring well	Monitor background water quality	1	Physicochemical
	90MW0020	Monitoring Well	Monitor background (in plume) water quality	1	Physicochemical
	90MW0085A,B	Monitoring well	Monitor water quality entering Snake Pond downgradient of ETR	2	Physicochemical
	90MW0015	Monitoring well	Monitor water quality entering Snake Pond downgradient of ETR	1	Chemical
	90MW0015	Monitoring well	Monitor water quality entering Snake Pond downgradient of ETR	1	Physicochemical
	90MP0060C,D,F	Multi-point well	Monitor water quality entering Snake Pond downgradient of ETR	3	Chemical
	90MP0060C,D,F	Multi-point well	Monitor water quality entering Snake Pond downgradient of ETR	3	Physicochemical
	ECMWSNP02S,D	Micro-well	Monitor water quality entering Snake Pond downgradient of ETR	2	Chemical
	ECMWSNP02S,D	Micro-well	Monitor water quality entering Snake Pond downgradient of ETR	2	Physicochemical
	ECMWSNP03S,D	Micro-well	Monitor water quality entering Snake Pond downgradient of ETR	1	Chemical
	ECMWSNP03S,D	Micro-well	Monitor water quality entering Snake Pond downgradient of ETR	1	Physicochemical
Triangle Pond (Reference Area)	ECMWTRP01S,D	Monitoring well	Monitor ambient groundwater quality entering Triangle Pond	2	Physicochemical
Peters Pond (Reference Area)	ECMWPTP01S,D	Monitoring well	Monitor ambient groundwater quality entering Peters Pond	2	Physicochemical

Table 3-4
Annual Synoptic Water Level Locations for FS-12 Phase II

Habitat	Location Identifier	Well Type	Rationale for Selecting Sample Location	Number of Measurements
Snake Pond	90ITW0002	Monitoring well	Quantify flux in regional groundwater flow	1
(Study Area)	90JB0006A,B	Monitoring well	Quantify flux in regional groundwater flow	2
	90JB0013	Monitoring well	Quantify flux in regional groundwater flow	1
	90JB0016	Monitoring well	Quantify flux in regional groundwater flow	1
	90JB0020	Monitoring well	Quantify flux in regional groundwater flow	1
	90JB0195	Monitoring well	Quantify flux in regional groundwater flow	1
	90MP0059A-F	Multiport well	Monitor vertical gradients adjacent to Snake Pond	6
	90MP0060A-F	Multiport well	Monitor vertical gradients adjacent to Snake Pond	6
	90MW0003	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0004	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0009	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0010	Monitoring well	Quantify water level flux and vertical gradient	1
	90MW0011	Monitoring well	Quantify water level flux and vertical gradient	1
	90MW0012	Monitoring well	Quantify water level flux and vertical gradient	1
	90MW0015	Monitoring well	Quantify water level flux and vertical gradient	1
	90MW0016	Monitoring well	Quantify water level flux and vertical gradient	1
	90MW0024	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0026	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0027	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0028	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0032	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0040	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0044	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0048	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0049	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0050	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0053	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0054	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0057	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0058	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0070	Monitoring well	Quantify flux in regional groundwater flow	1
	90MW0085A,B	Monitoring well	Monitor vertical gradients adjacent to Snake Pond	2
	90PZ01C01	Monitoring well	Quantify flux in regional groundwater flow	1
	90PZ0205	Monitoring well	Quantify flux in regional groundwater flow	1
	90PZ0207	Monitoring well	Quantify flux in regional groundwater flow	1
	90PZ0209	Monitoring well	Quantify flux in regional groundwater flow	1
	90PZ0212	Monitoring well	Quantify flux in regional groundwater flow	1
	90WT0005	Monitoring well	Quantify flux in regional groundwater flow	1
	90WT0008	Monitoring well	Quantify flux in regional groundwater flow	1
	ECMWSNP01	Monitoring well	Quantify flux in regional groundwater flow	1
	ECMWSNP02S,D	Micro-well	Quantify water flux under pond and vertical gradient	2
	ECMWSNP03S,D	Micro-well	Quantify water flux under pond and vertical gradient	2
	ECPZSNP01	Piezometer	Quantify shallow water flux downgradient of ETR	1
	ECPZSNP02	Piezometer	Quantify shallow water flux downgradient of ETR	1
	ECPZSNP10A,B	Monitoring well	Quantify water level flux and vertical gradient	2
	ECPZSNP11A,B	Monitoring well	Quantify water level flux and vertical gradient	2
	ECSGSNP01	Staff Gauge	Measure surface water elevation of study pond	1
Weeks Pond	ECPZWK01	Monitoring well	Quantify flux in regional groundwater flow	1
(Study Area)	ECPZWK02	Monitoring well	Quantify flux in regional groundwater flow	1
	ECSGWKP01	Staff Gauge	Measure surface water elevation of study pond	1

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Table 3-5
Surface Water and Sediment Sample Locations and Proposed Measurements for FS-12 Phase II

Habitat	Sample Location	Rationale for Selecting Sample Location	Surface Water			Sediment		
			Number of Samples	Parameters	Frequency	Number of Samples	Parameters	Frequency
Snake Pond (Study Area)	ECSNP02	Shallow sample near seepage meter location SSM8-A, within 30 ft of the shore; location of surface water discharge to groundwater; location outside influence of ETR system	1	Physicochemical analysis	6 times/yr*			
	ECSNP03	Characterize deeper portions of the pond and potential differences due to stratification	1 - 2 1 - 2	Physicochemical analysis	6 times/yr			
	ECSNP06	To characterize the pond and potential differences due to stratification	1 - 2	Physicochemical analysis	6 times/yr	1		
	ECSNP07	Along eastern shoreline (where the ETR system will be located) within 30 ft of the shore in area which may be influenced by ETR system, near SMP1-C	1 1	Chemical analysis Physicochemical analysis	Quarterly 6 times/yr	1	Chemical analysis	As warranted
	ECSNP08	Along eastern shoreline (where the ETR system will be located) within 30 ft of the shore in area which may be influenced by ETR system, between SMP2-B and C	1 1	Chemical analysis Physicochemical analysis	Quarterly 6 times/yr	1	Chemical analysis	As warranted
	ECSGSNP01 Staff gauge	Characterize pond hydraulics	1	Water level	Weekly/ Biweekly	NA	NA	NA
Triangle Pond (Reference Area)	ECTRP01	Shallow sample along the northwestern shore; location of groundwater discharge to surface water	1	Physicochemical analysis	6 times/yr			
	ECTRP03	Shallow sample along the southeastern shore; location of surface water discharge to groundwater	1	Physicochemical analysis	6 times/yr			
	ECTRP04	Shallow sample near TSM-1 seepage meter series; location of groundwater discharge to surface water	1	Physicochemical analysis	6 times/yr			
	ECTRP05	Characterize deeper portions of the pond and potential differences due to stratification	1 - 2	Physicochemical analysis	6 times/yr			
	ECTRP06	Characterize the pond and potential differences due to stratification	1 - 2	Physicochemical analysis	6 times/yr			
	ECSGTRP01 Staff gauge	Characterize pond hydraulics	1	Water level	Weekly/ Biweekly	NA	NA	NA
Peters Pond (Reference Area)	ECPTP01	Shallow sample; possible location of surface water discharge to groundwater	1	Physicochemical analysis	6 times/yr			
	ECPTP02	Shallow sample; possible location of groundwater discharge to surface water	1	Physicochemical analysis	6 times/yr			
	ECPTP03	Shallow sample; possible location of groundwater discharge to surface water	1	Physicochemical analysis	6 times/yr			

Table 3-5
Surface Water and Sediment Sample Locations and Proposed Measurements for FS-12 Phase II

Habitat	Sample Location	Rationale for Selecting Sample Location	Surface Water			Sediment		
			Number of Samples	Parameters	Frequency	Number of Samples	Parameters	Frequency
Peters Pond (Reference Area) (continued)	ECPTP04	Characterize deeper portions of the pond and potential differences due to stratification	1 - 2	Physicochemical analysis	6 times/yr			
	ECPTP05	Characterize deeper portions of the pond and potential differences due to stratification	1 - 2	Physicochemical analysis	6 times/yr			
	ECSGPTP01 Staff gauge	Characterize pond hydraulics	1	Water level	Weekly/ Biweekly	NA	NA	NA

NA - Not applicable

* 6 times/yr = sampling scheduled for February, May, June, August, September, and November

Table 3-6
Biological Survey Sampling Locations Associated with FS-12 Phase II

Habitat Type	Survey Type	Sample Location	Rationale for Selecting Sample Location	Survey Effort	Survey Frequency
Snake Pond (Study Area)	Shoreline vegetation	North shore of the pond	Characterize coastal plain pondshore community	3 transects	Annually
		West shore of the pond	Characterize coastal plain pondshore community	3 transects	Annually
		East shore of the pond	Characterize coastal plain pondshore community	3 transects	Annually
	Aquatic vegetation	North shore of the pond	Characterize coastal plain pondshore community	3 transects	Annually
		West shore of the pond	Characterize coastal plain pondshore community	3 transects	Annually
		East shore of the pond	Characterize coastal plain pondshore community	3 transects	Annually
	Phytoplankton	ECSNP02	Shallow sample near seepage meter location SSM8-A, within 30 ft of the shore; location of surface water discharge to groundwater; location outside influence of ETR system	3 sample depths	4 times/yr*
		ECSNP03	Characterize deeper portions of the pond and potential differences due to stratification	3 sample depths	4 times/yr
		ECSNP06	To characterize the pond and potential differences due to stratification	3 sample depths	4 times/yr
		ECSNP07	Along eastern shoreline (where the ETR system will be located) within 30 ft of the shore in area which may be influenced by ETR system, near SMP1-C	3 sample depths	4 times/yr
		ECSNP08	Along eastern shoreline (where the ETR system will be located) within 30 ft of the shore in area which may be influenced by ETR system, between SMP2-B and C	3 sample depths	4 times/yr
	Zooplankton	ECSNP02	Shallow sample near seepage meter location SSM8-A, within 30 ft of the shore; location of surface water discharge to groundwater; location outside influence of ETR system	1 sample of entire water column	4 times/yr
		ECSNP03	Characterize deeper portions of the pond and potential differences due to stratification	1 sample of entire water column	4 times/yr
		ECSNP06	To characterize the pond and potential differences due to stratification	1 sample of entire water column	4 times/yr
		ECSNP07	Along eastern shoreline (where the ETR system will be located) within 30 ft of the shore in area which may be influenced by ETR system, near SMP1-C	1 sample of entire water column	4 times/yr
		ECSNP08	Along eastern shoreline (where the ETR system will be located) within 30 ft of the shore in area which may be influenced by ETR system, between SMP2-B and C	1 sample of entire water column	4 times/yr
	Benthic macroinvertebrates	ECSNP02	Shallow sample near seepage meter location SSM8-A, within 30 ft of the shore; location of surface water discharge to groundwater; location outside influence of ETR system	1 sample	Semiannually
		ECSNP03	Characterize deeper portions of the pond	1 sample	Semiannually
		ECSNP06	To characterize the pond	1 sample	Semiannually
		ECSNP07	Along eastern shoreline (where the ETR system will be located) within 30 ft of the shore in area which may be influenced by ETR system, near SMP1-C	1 sample	Semiannually
		ECSNP08	Along eastern shoreline (where the ETR system will be located) within 30 ft of the shore in area which may be influenced by ETR system, between SMP2-B and C	1 sample	Semiannually
		5 additional locations TBD	TBD - depending on substrate composition	1 sample per location	Semiannually

Table 3-6
Biological Survey Sampling Locations Associated with FS-12 Phase II

Habitat Type	Survey Type	Sample Location	Rationale for Selecting Sample Location	Survey Effort	Survey Frequency
Snake Pond (Study Area) (continued)	Threatened, endangered, and special status species	Snake Pond Area	NA	Specific to organisms surveyed	Annually
Triangle Pond (Reference Area)	Shoreline vegetation	Northwest shore of the pond	Characterize coastal plain pondshore community	3 transects	Annually
		East shore of western leg of pond	Characterize coastal plain pondshore community	3 transects	Annually
		West shore of eastern leg of pond	Characterize coastal plain pondshore community	3 transects	Annually
	Aquatic vegetation	Northwest shore of the pond	Characterize coastal plain pondshore community	3 transects	Annually
		East shore of western leg of pond	Characterize coastal plain pondshore community	3 transects	Annually
		West shore of eastern leg of pond	Characterize coastal plain pondshore community	3 transects	Annually
	Phytoplankton	ECTRP01	Shallow sample along the northwesternshore; location of groundwater discharge to surface water	3 sample depths	4 times/yr
		ECTRP03	Shallow sample along the southeastern shore; location of surface water discharge to groundwater	3 sample depths	4 times/yr
		ECTRP04	Shallow sample near TSM-1 seepage meter series; location of groundwater discharge to surface water	3 sample depths	4 times/yr
		ECTRP05	Characterize deeper portions of the pond and potential differences due to stratification	3 sample depths	4 times/yr
		ECTRP06	Characterize the pond and potential differences due to stratification	3 sample depths	4 times/yr
	Zooplankton	ECTRP01	Shallow sample along the northwestern shore; location of groundwater discharge to surface water	1 sample of entire water column	4 times/yr
		ECTRP03	Shallow sample along the southeastern shore; location of surface water discharge to groundwater	1 sample of entire water column	4 times/yr
		ECTRP04	Shallow sample near TSM-1 seepage meter series; location of groundwater discharge to surface water	1 sample of entire water column	4 times/yr
		ECTRP05	Characterize deeper portions of the pond and potential differences due to stratification	1 sample of entire water column	4 times/yr
		ECTRP06	Characterize the pond and potential differences due to stratification	1 sample of entire water column	4 times/yr
	Benthic macroinvertebrates	ECTRP01	Shallow sample along the northwestern shore; location of groundwater discharge to surface water	1 sample	Semiannually
		ECTRP03	Shallow sample along the southeastern shore; location of surface water discharge to groundwater	1 sample	Semiannually
		ECTRP04	Shallow sample near TSM-1 seepage meter series; location of groundwater discharge to surface water	1 sample	Semiannually
		ECTRP05	Characterize deeper portions of the pond and potential differences due to stratification	1 sample	Semiannually
		ECTRP06	Characterize the pond and potential differences due to stratification	1 sample	Semiannually
		5 additional locations TBD	TBD - based on substrate composition	1 sample per location	Semiannually
	Threatened, endangered, and special status species	TBD	NA	3 transects	Annually

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Table 3-6
Biological Survey Sampling Locations Associated with FS-12 Phase II

Habitat Type	Survey Type	Sample Location	Rationale for Selecting Sample Location	Survey Effort	Survey Frequency
Peters Pond (Reference Area)	Shoreline vegetation	Southwest shore of the pond	Characterize coastal plain pondshore community	3 transects per location	Annually
		South shore of the pond	Characterize coastal plain pondshore community	3 transects per location	Annually
	Aquatic vegetation	Southwest shore of the pond	Characterize coastal plain pondshore community	3 transects per location	Summer
		South shore of the pond	Characterize coastal plain pondshore community	3 transects per location	Summer
	Phytoplankton	ECPTP01	Identify populations in shallow water; possible location of surface water discharge to groundwater	3 sample depths	4 times/yr
		ECPTP02	Identify populations in shallow water; possible location of groundwater discharge to surface water	3 sample depths	4 times/yr
		ECPTP03	Identify populations in shallow water; possible location of groundwater discharge to surface water	3 sample depths	4 times/yr
		ECPTP04	Identify populations in deeper portions of the pond and potential differences due to stratification	3 sample depths	4 times/yr
		ECPTP05	Identify populations in deeper portions of the pond and potential differences due to stratification	3 sample depths	4 times/yr
	Zooplankton	ECPTP01	Identify populations in shallow water; possible location of surface water discharge to groundwater	1 sample of entire water column	4 times/yr
		ECPTP02	Identify populations in shallow water; possible location of groundwater discharge to surface water	1 sample of entire water column	4 times/yr
		ECPTP03	Identify populations in shallow water; possible location of groundwater discharge to surface water	1 sample of entire water column	4 times/yr
		ECPTP04	Identify populations in deeper portions of the pond and potential differences due to stratification	1 sample of entire water column	4 times/yr
		ECPTP05	Identify populations in deeper portions of the pond and potential differences due to stratification	1 sample of entire water column	4 times/yr
	Benthic macroinvertebrates	ECPTP01	Identify populations in shallow water; possible location of surface water discharge to groundwater	1 sample	Semiannually
		ECPTP02	Identify populations in shallow water; possible location of groundwater discharge to surface water	1 sample	Semiannually
		ECPTP03	Identify populations in shallow water; possible location of groundwater discharge to surface water	1 sample	Semiannually
		ECPTP04	Identify populations in deeper portions of the pond	1 sample	Semiannually
		ECPTP05	Identify population in deeper portions of the pond	1 sample	Semiannually
		5 additional locations TBD	To be determined	1 sample per location	Semiannually
Peters Pond (Reference Area) (continued)	Threatened and endangered species and species of special concern	To be determined	To be determined	Specific to organisms being surveyed	Annually

NA - Not applicable

TBD - To be determined

* 4 times/yr = sampling scheduled for May, June, August, and September

Table 3-7
Ecological Criteria Guidelines for Evaluating Impacts Associated with the FS-12 Groundwater Treatment System

Ecological Characteristic/ Attribute of Concern	Ecosystem of Concern	Proposed Measurement	Ecological Criteria Guideline Value
TIER I CRITERIA			
pH	Ponds Vernal pools Wetlands Rivers Estuaries	Measured as sampling event mean (epilimnion in a stratified system).	2 standard deviations from the mean change in pH based on comparison of appropriate reference ecosystems to account for seasonal and climatic variations.
Dissolved Oxygen (DO)	Ponds Vernal pools Wetlands Rivers Estuaries	Measured as sampling event mean (epilimnion in a stratified system).	20 percent change in DO based on comparison of appropriate reference ecosystems to account for seasonal and climatic variations.
Temperature	Ponds Vernal pool Wetlands Rivers Estuaries	Measured as sampling event mean (epilimnion in a stratified system).	20 percent change in temperature based on comparison of appropriate reference ecosystems to account for seasonal and climatic variations.
Water level	Ponds Vernal pools Wetlands Rivers Estuaries	Sampling event mean based on groundwater level and staff gauge measurements in study area and reference ecosystems.	Water level will not be caused to change more than 0.5 feet in ponds and 0.2 feet in vernal pools when compared to the appropriate reference ecosystems.
Dissolved Organic Carbon (DOC)	Ponds Vernal pools Wetlands Rivers Estuaries	Measured as sampling event mean (epilimion in a stratified system).	20 percent change in DOC based on comparison of appropriate reference ecosystems to account for seasonal and climatic variations.

Table 3-7
Ecological Criteria Guidelines for Evaluating Impacts Associated with the FS-12 Groundwater Treatment System

Ecological Characteristic/ Attribute of Concern	Ecosystem of Concern	Proposed Measurement	Ecological Criteria Guideline Value
TIER II CRITERIA			
Shoreline vegetation community structure	Ponds Vernal pools	Sampling event measurements of relative abundance, species richness, dominant species, and percent cover.	20 percent change of spatial extent. Maintenance of 80 percent of dominant species. 20 percent change in species richness. Include comparison of appropriate reference ecosystems to account for seasonal and climatic variations.
Aquatic vegetation community structure	Ponds Vernal pools	Sampling event measurements of relative abundance, species richness, dominant species, and percent cover.	20 percent change of spatial extent. Maintenance of 80 percent of dominant species. 20 percent change in species richness. Include comparison of appropriate reference ecosystems to account for seasonal and climatic variations.
Wetland vegetation community structure	Wetlands	Sampling event measurements of relative abundance, species richness, dominant species, percent cover, and wetland indicators.	20 percent change of spatial extent. Maintenance of 80 percent of dominant species. 20 percent change in species richness. Include comparison of appropriate reference ecosystems to account for seasonal and climatic variations.

Table 3-7
Ecological Criteria Guidelines for Evaluating Impacts Associated with the FS-12 Groundwater Treatment System

Ecological Characteristic/ Attribute of Concern	Ecosystem of Concern	Proposed Measurement	Ecological Criteria Guideline Value
TIER II CRITERIA	**(continued)**		
Phytoplankton concentration	Ponds Estuaries	Sampling event measurements of chlorophyll *a*.	20 percent change in concentration. Include comparison of appropriate reference ecosystems to account for seasonal and climatic variations.
Benthic macroinvertebrates	Ponds Estuaries	Sampling event measurements of speciation, relative abundance, species richness, species diversity, and dominant species of benthic macroinvertebrates.	20 percent change in concentration. Include comparison of appropriate reference ecosystems to account for seasonal and climatic variations.
Trophic state	Ponds Estuaries	Sampling event measurements of chlorophyll *a* levels, speciation, relative abundance, species richness, species diversity, and dominant species of phytoplankton, zooplankton, and benthic macroinvertebrates; concentrations of total phosphorous, total Kjeldahl nitrogen, and micronutrients and Secchi depth.	An increase in the trophic state.
Amphibian reproduction	Vernal pools Wetlands	Sampling event measurements of relative abundance of adult species, relative abundance of larvae and egg clusters, and growth rate of larvae.	20 percent change in relative abundance as measured as larval and egg mass abundance. Include comparison of appropriate reference ecosystems to account for seasonal and climatic variations.

Table 3-7
Ecological Criteria Guidelines for Evaluating Impacts Associated with the FS-12 Groundwater Treatment System

Ecological Characteristic/ Attribute of Concern	Ecosystem of Concern	Proposed Measurement	Ecological Criteria Guideline Value
TIER II CRITERIA (continued)			
Impact to threatened and endangered species and species of special concern	Ponds Vernal pool Wetlands Rivers Estuaries	Specific to organism being evaluated. Requires nondestructive sampling techniques.	The presence of threatened and endangered species and species of special concern will not be caused to change.

TABLE 4-1
FS-12 Surface Water and Groundwater Elevations
Comparison to Ecological Criteria Guidelines

Surface Water Elevations (ft)

Pond	Class	n	Mean	sd	min	max	LCL	UCL	Difference	ECG	ECG Exceedence?
Snake	Study	49	71.00	0.96	69	72.3	70.72	71.27	0.27	> 0.5	no
Peters	Reference	47	71.65	0.64	70.48	72.3	71.46	71.83	0.18	> 0.5	no
Triangle	Reference	48	67.49	0.64	66.4	68.18	67.30	67.67	0.18	> 0.5	no
Weeks	Study	45	70.73	0.92	69.09	71.93	70.46	71.01	0.28	> 0.5	no

Groundwater Elevations (ft)

Well ID	Relative Location	n	Mean	sd	min	max	LCL	UCL	Difference	ECG	ECG Exceedence?
90MW0020	upgradient	15	71.02	1.10	69.31	72.35	70.41	71.63	0.61	> 0.5	yes
90MW0058	downgradient	44	69.95	0.51	68.1	72.09	69.80	70.11	0.16	> 0.5	no

ECG = Ecological Criteria Guideline
LCL = 95% Lower Confidence Limit
max = maximum value observed
min = minimum value observed
n = number of observations
sd = standard deviation of population
UCL = 95% Upper Confidence Limit
Well ID = Well Identification

TABLE 4-2
FS12 Groundwater
Analysis of Variance Results
Tier I Parameters

	Temperature (°C)			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Rel.Location				10.1
Upgradient	12.7	21	Reference	
Downgradient	12.3	130	Reference	
Reference	14.2	16	Downgradient & Upgradient	
Season				27.2
Winter	10	12	Spring, Fall, Summer	
Spring	12.6	17	Winter, Summer	
Summer	13.7	50	Winter,Spring,Fall	
Fall	12.2	87	Winter, Summer	
Phase				0.16
Phase I	12.4	130	none	
Phase II	12.6	37	none	

	Dissolved Oxygen (mg/L)			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Rel.Location				14.98
Upgradient	6.81	21	Downgradient	
Downgradient	9.82	129	Upgradient & Reference	
Reference	8.27	16	Downgradient	
Season				2.86
Winter	10.57	12	Spring	
Spring	8.35	17	Winter	
Summer	9.29	49	none	
Fall	9.27	87	none	
Phase				0.004
Phase I	9.32	36	none	
Phase II	9.28	130	none	

	pH			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Rel.Location				42.4
Upgradient	5.20	21	Reference & Downgradient	
Downgradient	6.36	130	Upgradient & Reference	
Reference	5.98	16	Upgradient & Downgradient	
Season				3.09
Winter	5.94	12	none	
Spring	6.25	17	none	
Summer	6.30	50	none	
Fall	6.12	87	none	
Phase				1.00
Phase I	6.28	37	none	
Phase II	6.14	130	none	

	Dissolved Organic Carbon (mg/L)			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Rel.Location				9.92
Upgradient	0.98	19	Downgradient	
Downgradient	0.45	73	Upgradient	
Reference	0.73	16	none	
Season				5.20
Winter	0.83	12	none	
Spring	0.77	20	none	
Summer	0.41	30	none	
Fall	0.56	46	none	
Phase				3.75
Phase I	0.33	21	Phase II	
Phase II	0.65	87	Phase I	

LSD=Least Significant Difference mg/L=milligrams per liter
n=number of observations

Table 4-3
FS-12 Treatment System Monitoring
Groundwater

Groundwater Tests Phase I	Downgradient		Reference		Tests			Two Sample Tests				
Tier I Parameter	n	mean	n	mean	Omnibus Normality	Modified Levene Equal Variance	Test	Probability Level	Result	Difference	Ecological Criteria Guideline	Ecological Criteria Guideline Exceedence
Dissolved Organic Carbon (mg/L)	19	0.34	2	0.26	Reject	Cannot Reject	Wilcoxon Rank-Sum	0.7	Accept Ho	23.5%	> 20%	Yes
pH	35	6.3	2	6.1	Reject	Cannot Reject	Wilcoxon Rank-Sum	0.81	Accept Ho	0.32sd	> 2.0 sd	No
Temperature (°C)	35	12.13	2	16.74	Cannot Reject	Reject	Aspin Welch	0.40	Accept Ho	38.0%	> 20%	Yes
Dissolved Oxygen (mg/L)	34	9.58	2	4.83	Reject	Cannot Reject	Wilcoxon Rank-Sum	0.06	Accept Ho	49.6%	> 20%	Yes

Groundwater Tests Phase II	Downgradient		Reference		Tests			Two Sample Tests				
Tier I Parameter	n	mean	n	mean	Omnibus Normality	Modified Levene Equal Variance	Test	Probability Level	Result	Difference	Ecological Criteria Guideline	Ecological Criteria Guideline Exceedence
Dissolved Organic Carbon (mg/L)	54	0.5	14	0.8	Reject	Cannot Reject	Wilcoxon Rank-Sum	0.13	Accept Ho	60.5%	> 20%	Yes
pH	95	6.38	14	5.96	Reject	Cannot Reject	Wilcoxon Rank-Sum	0	Reject Ho	1.08sd	> 2.0 sd	No
Temperature (°C)	95	12.3	14	13.89	Reject	Reject	Kolmogorov-Smirnov	0.03	Reject Ho	12.8%	> 20%	No
Dissolved Oxygen (mg/L)	95	9.9	14	8.76	Reject	Reject	Kolmogorov-Smirnov	0.03	Reject Ho	11.5%	> 20%	No

° C=degrees Celsius
Ho=null hypothesis
mg/L=milligrams per liter
n=number of observations
sd =standard deviation
>=greater than

Table 4-4
FS-12 Descriptive Statistics for Physicochemical Parameters

Oxidation/Reduction Potential (mV)

Groundwater

Rel.Location	Phase	n	mean	sd	min	max	LCL	UCL
Upgradient	I							
	II	21	218.3	116.8	21.6	362.7	165.1	271.5
Downgradient	I	35	132.0	91.3	-59.2	278.1	100.6	163.3
	II	95	132.3	99.0	45.4	385.2	112.1	152.5
Reference	I	2	205.9	6.3	201.4	210.3	149.3	262.4
	II	14	219.4	22.4	184.9	264.9	206.5	232.3

Surface Water

Class	Phase	n	mean	sd	min	max	LCL	UCL
Study	I	157	165.1	48.6	23	254	157.4	172.8
	II	172	259.2	79.7	22.7	431.6	247.2	271.2
Reference	I	270	136.4	72.3	-97	258	127.7	145.0
	II	553	180.5	80.2	-15.1	392.9	173.8	187.2

mV=milliVolts

Specific Conductance (µS/cm)

Groundwater

Rel.Location	Phase	n	mean	sd	min	max	LCL	UCL
Upgradient	I							
	II	21	82.6	17.8	60	110	75.5	90.7
Downgradient	I	35	60.6	10.9	39	82	56.9	64.4
	II	95	61.9	10.4	39	87	59.8	64.0
Reference	I	2	101	31.1	79	123	-178.5	380.5
	II	14	102.9	29.0	72	181	86.1	119.6

Surface Water

Class	Phase	n	mean	sd	min	max	LCL	UCL
Study	I	185	56.0	5.2	47	66	55.3	56.8
	II	172	55.0	3.0	49	66	54.6	55.5
Reference	I	327	71.0	9.9	56	94	69.9	72.0
	II	553	72.7	10.8	55	102	71.8	73.6

µS/cm = microsiemens/centimeter
LCL = 95% Lower Confidence Level
max = maximum value observed
min = minimum value observed
n = number of observations
sd = standard deviation of population
UCL = 95% Upper Confidence Level

Table 4-4
FS-12 Descriptive Statistics for Physicochemical Parameters

Turbidity (NTUs)

Groundwater

Rel.Location	Phase	n	mean	sd	min	max	LCL	UCL
Upgradient	I							
	II	21	0.71	0.93	0	3.4	0.29	1.13
Downgradient	I	35	420.6	664.7	0	2364	192.3	648.9
	II	95	93.8	300.3	0	1882.4	32.6	155.0
Reference	I	2	0.25	0.35	0	0.5	-2.93	3.43
	II	14	0.56	0.62	0	1.6	0.20	0.91

Surface Water

Class	Phase	n	mean	sd	min	max	LCL	UCL
Study	I	127	0.73	2.34	0	17.2	0.31	1.14
	II	170	1.01	2.76	0	31.5	0.59	1.43
Reference	I	269	1.17	1.40	0	10	1.00	1.33
	II	549	1.31	1.47	0	17.5	1.18	1.44

NTUs=nephelometric turbidity units

Total Suspended Solids (mg/L)

Groundwater

Rel.Location	Phase	n	mean	sd	min	max	LCL	UCL
Upgradient	I							
	II	12	1.04	0.63	0.4	2.5	0.64	1.44
Downgradient	I	16	22.7	47.5	1.27	163	0	48.0
	II	61	3.21	4.20	0.05	20	2.14	4.29
Reference	I	2	1.27	0	1.27	1.27	NA	NA
	II	10	0.68	0.52	0.05	1.27	0.31	1.06

Surface Water

Class	Phase	n	mean	sd	min	max	LCL	UCL
Study	I	35	24.1	93.7	1.27	501	0	56.3
	II	30	2.95	7.52	0.6	42.2	0.15	5.76
Reference	I	51	4.66	15.8	1.27	114	0.22	9.09
	II	62	1.42	0.68	0.05	3	1.25	1.59

LCL = 95% Lower Confidence Level
max = maximum value observed
mg/L = milligrams per liter
min = minimum value observed
n = number of observations
NA = not applicable
sd = standard deviation of population
UCL = 95% Upper Confidence Level

Table 4-4
FS-12 Descriptive Statistics for Physicochemical Parameters

Total Dissolved Solids (mg/L)

Groundwater

Rel. Location	Phase	n	mean	sd	min	max	LCL	UCL
Upgradient	I							
	II	10	55.8	24.0	15	85	38.7	73.0
Downgradient	I	14	43.1	13.7	26	76	35.2	51.0
	II	42	49.4	18.5	2.48	132	43.6	55.1
Reference	I	2	65.0	21.2	50	80	0	255.6
	II	10	78.3	25.5	48	134	60.0	96.5

Surface Water

Class	Phase	n	mean	sd	min	max	LCL	UCL
Study	I	35	35.7	16.9	8	90	29.9	41.5
	II	30	95.1	128.4	24	567	47.2	143.1
Reference	I	51	40.9	17.4	6	85	36.1	45.8
	II	62	70.4	87.0	14	667	48.4	92.5

mg/L=milligrams per liter

Total Organic Carbon (mg/L)

Groundwater

Rel. Location	Phase	n	mean	sd	min	max	LCL	UCL
Upgradient	I							
	II	18	0.82	0.77	0.17	3.6	0.44	1.20
Downgradient	I	16	0.27	0.02	0.26	0.3	0.26	0.28
	II	49	0.23	0.14	0.1	0.67	0.19	0.27
Reference	I	2	0.26	0	0.26	0.26	NA	NA
	II	10	0.35	0.17	0.17	0.66	0.23	0.47

Surface Water

Class	Phase	n	mean	sd	min	max	LCL	UCL
Study	I	35	1.20	1.28	0.26	5.06	0.76	1.64
	II	36	1.67	0.65	0.26	2.36	1.45	1.89
Reference	I	52	0.92	1.00	0.26	4.29	0.64	1.20
	II	67	1.70	0.71	0.26	3.23	1.53	1.87

LCL = 95% Lower Confidence Level
max = maximum value observed
mg/L = milligrams per liter
min = minimum value observed
n = number of observations
NA = not applicable
sd = standard deviation of population
UCL = 95% Upper Confidence Level

Table 4-4
FS-12 Descriptive Statistics for Physicochemical Parameters

Alkalinity (mg/L)

Groundwater

Rel.Location	Phase	n	mean	sd	min	max	LCL	UCL
Upgradient	I							
	II	18	10.1	9.45	1.28	26.3	5.44	14.8
Downgradient	I	14	6.68	3.31	3.66	14.6	4.76	8.59
	II	54	10.6	5.72	0.5	24.5	8.99	12.1
Reference	I	2	19.1	20.3	4.71	33.4	0	201.4
	II	14	13.6	15.1	3.43	56.9	4.89	22.3

Surface Water

Class	Phase	n	mean	sd	min	max	LCL	UCL
Study	I	35	4.12	6.38	0.5	33.6	1.93	6.31
	II	36	2.45	0.86	0.85	5.3	2.15	2.74
Reference	I	52	4.81	3.34	0.44	11.9	3.88	5.74
	II	75	6.24	7.77	0.95	65.1	4.45	8.03

mg/L=milligrams per liter

Dissolved Inorganic Carbon (mg/L)

Groundwater

Rel.Location	Phase	n	mean	sd	min	max	LCL	UCL
Upgradient	I							
	II	16	12.9	4.76	6.67	19.3	10.4	15.5
Downgradient	I	15	3.27	1.10	1.80	6.03	2.65	3.88
	II	51	4.29	1.21	2	9.31	3.95	4.63
Reference	I	2	11.2	9.07	4.78	17.6	0	92.6
	II	14	9.12	6.64	4.32	29.9	5.29	13.0

Surface Water

Class	Phase	n	mean	sd	min	max	LCL	UCL
Study	I	25	0.69	0.67	0.05	2.84	0.42	0.97
	II	36	0.87	0.51	0.5	3.26	0.70	1.05
Reference	I	35	1.38	0.98	0.26	2.66	1.04	1.71
	II	73	1.65	0.99	0.5	4.01	1.42	1.88

LCL = 95% Lower Confidence Level
max = maximum value observed
mg/L = milligrams per liter
min = minimum value observed
n = number of observations
sd = standard deviation of population
UCL = 95% Upper Confidence Level

TABLE 4-5
FS-12 Surface Water
Analysis of Variance Results
Tier I Parameters

	Temperature (°C)			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Class				1.41
Study	17.6	357	Reference	
Reference	19.1	880	Study	
Season				46.0
Winter	NS	NS		
Spring	15.2	317	Summer	
Summer	23.2	504	Spring,Fall	
Fall	15.6	416	Summer	
Phase				2.70
Phase I	19.7	512	Phase II	
Phase II	17.9	725	Phase I	
Limnion				3.58
Epilimnion	19.1	1041	hypolimnion	
Hypolimnion	16.2	196	epilimnion	

	Dissolved Oxygen (mg/L)			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Class				0.18
Study	9.20	357	none	
Reference	9.00	880	none	
Season				21.9
Winter	NS	NS		
Spring	10.4	317	Summer,Fall	
Summer	7.95	504	Spring,Fall	
Fall	9.40	416	Spring,Summer	
Phase				0.01
Phase I	9.03	512	none	
Phase II	9.08	725	none	
Limnion				4.83
Epilimnion	9.25	1041	hypolimnion	
Hypolimnion	7.94	196	epilimnion	

	pH			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Class				13.5
Study	6.60	357	Reference	
Reference	6.93	877	Study	
Season				5.08
Winter	NS	NS		
Spring	6.98	317	Summer,Fall	
Summer	6.83	504	Spring,Fall	
Fall	6.74	413	Spring,Summer	
Phase				0.73
Phase I	6.80	512	Phase II	
Phase II	6.87	722	Phase I	
Limnion				0.04
Epilimnion	6.83	1038	none	
Hypolimnion	6.86	196	none	

	Dissolved Organic Carbon (mg/L)			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Class				1.33
Study	1.70	64	none	
Reference	2.02	121	none	
Season				3.36
Winter	NS	NS		
Spring	1.58	51	Summer	
Summer	2.17	77	Spring	
Fall	1.86	57	none	
Phase				0.99
Phase I	1.75	76	none	
Phase II	2.02	109	none	
Limnion				0.31
Epilimnion	1.88	154	none	
Hypolimnion	2.07	31	none	

NS=Not Sampled n=number of observations LSD=Least Significant Difference mg/L=milligrams per liter

Table 4-6
FS-12 Treatment System Monitoring
Surface Water

Surfacewater Tests Phase I	Study		Reference		Tests			Two-Sample Tests				
Tier I Parameter	n	mean	n	mean	Omnibus Normality	Modified Levene Equal Variance	Test	Probability Level	Result	Difference	Ecological Criteria Guideline	Ecological Criteria Guideline Exceedance
Dissolved Organic Carbon (mg/L)	28	1.48	42	1.96	N/A	Cannot Reject	Equal Variance	0.264	Accept Ho	32.5%	> 20%	Yes
pH	176	6.74	270	6.84	N/A	Reject	Aspin Welch	0	Reject Ho	0.42sd	> 2.0 sd	No
Temperature (°C)	176	17.8	270	21.7	N/A	Reject	Aspin Welch	0	Reject Ho	25.0%	> 20%	Yes
Dissolved Oxygen (mg/L)	176	9.55	270	9.06	N/A	Reject	Aspin Welch	0.035	Reject Ho	5.17%	> 20%	No

Surfacewater Tests Phase II	Study		Reference		Tests			Two-Sample Tests				
Tier I Parameter	n	mean	n	mean	Omnibus Normality	Modified Levene Equal Variance	Test	Probability Level	Result	Difference	Ecological Criteria Guideline	Ecological Criteria Guideline Exceedence
Dissolved Organic Carbon (mg/L)	34	1.92	65	2.03	N/A	Cannot Reject	Equal-Variance	0.597	Accept Ho	5.70%	> 20%	No
pH	151	6.55	441	6.96	N/A	Cannot Reject	Equal-Variance	0	Reject Ho	1.05sd	> 2.0 sd	No
Temperature (°C)	151	18.1	444	18.6	N/A	Cannot Reject	Equal-Variance	0.305	Accept Ho	2.55%	> 20%	No
Dissolved Oxygen (mg/L)	151	9.35	444	9.24	N/A	Reject	Aspin-Welch	0.205	Accept Ho	1.19%	> 20%	No

° C = degrees Celsius
Ho = null hypothesis
mg/L = milligrams per liter
n = number of observations
sd = standard deviation
N/A = Not Applicable
>=greater than

Table 4-7
Snake Pond Phase II 1997 - 1998 Phytoplankton Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECSNP02	Aug-97	5.56	5.43	1.03	0.64	0.41	2.36
ECSNP03	Aug-97	5.02	4.89	0.87	0.67	0.34	2.43
ECSNP06	Aug-97	4.50	4.36	0.92	0.82	0.55	2.85
ECSNP07	Aug-97	9.08	8.97	0.98	0.49	0.31	2.14
ECSNP08	Aug-97	4.41	4.27	0.92	0.65	0.58	2.24
Combined	Aug-97	9.01	8.90	0.76	0.78	0.15	3.47
ECSNP02	Sep-97	4.24	4.11	0.62	0.31	0.34	1.10
ECSNP03	Sep-97	3.88	3.75	0.57	0.44	0.33	1.52
ECSNP06	Sep-97	4.21	4.08	0.72	0.29	0.30	0.99
ECSNP07	Sep-97	NA	NA	NA	NA	NA	NA
ECSNP08	Sep-97	3.36	3.26	0.27	0.27	0.61	0.92
Combined	Sep-97	5.82	5.71	0.49	0.28	0.37	1.13
ECSNP02	Oct-97	5.20	5.06	0.98	0.48	0.29	1.74
ECSNP03	Oct-97	4.32	4.20	0.67	0.45	0.36	1.60
ECSNP06	Oct-97	4.77	4.64	0.83	0.44	0.33	1.59
ECSNP07	Oct-97	4.66	4.53	0.82	0.51	0.24	1.82
ECSNP08	Oct-97	4.31	4.19	0.55	0.44	0.29	1.57
Combined	Oct-97	11.18	11.07	0.96	0.53	0.13	2.45
ECSNP02	May-98	1.80	1.70	0.12	0.43	0.53	1.24
ECSNP03	May-98	3.04	2.93	0.28	0.51	0.40	1.69
ECSNP06	May-98	2.28	2.17	0.18	0.40	0.54	1.23
ECSNP07	May-98	2.77	2.65	0.36	0.75	0.16	2.34
ECSNP08	May-98	2.57	2.46	0.26	0.56	0.33	1.76
Combined	May-98	3.73	3.64	0.17	0.43	0.44	1.61
ECSNP02	Jun-98	1.78	1.68	0.11	0.41	0.46	1.19
ECSNP03	Jun-98	1.82	1.71	0.16	0.40	0.52	1.14
ECSNP06	Jun-98	1.95	1.85	0.15	0.36	0.54	1.07
ECSNP07	Jun-98	2.88	2.79	0.19	0.56	0.27	1.89
ECSNP08	Jun-98	2.33	2.23	0.14	0.49	0.40	1.56
Combined	Jun-98	4.06	3.97	0.14	0.42	0.41	1.61
ECSNP02	Aug-98	2.99	2.89	0.23	0.66	0.17	2.23
ECSNP03	Aug-98	3.04	2.94	0.25	0.66	0.19	2.23
ECSNP06	Aug-98	3.18	3.08	0.27	0.68	0.15	2.33
ECSNP07	Aug-98	2.91	2.80	0.26	0.73	0.12	2.41
ECSNP08	Aug-98	3.21	3.10	0.28	0.68	0.14	2.31
Combined	Aug-98	4.33	4.24	0.19	0.66	0.13	2.54
ECSNP02	Sep-98	2.08	1.98	0.16	0.52	0.32	1.55
ECSNP03	Sep-98	2.03	1.91	0.26	0.68	0.23	1.93
ECSNP06	Sep-98	2.88	2.77	0.28	0.79	0.11	2.58
ECSNP07	Sep-98	2.59	2.50	0.11	0.58	0.22	1.96
ECSNP08	Sep-98	2.01	1.89	0.25	0.59	0.26	1.67
Combined	Sep-98	5.02	4.93	0.18	0.60	0.15	2.43

Combined - calculation of index combining all pond data collected during the sampling event.

NA - not available

Table 4-8
Triangle Pond Phase II 1997 - 1998 Phytoplankton Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECTRP01	Aug-97	3.62	3.52	0.20	0.60	0.19	2.19
ECTRP03	Aug-97	2.70	2.61	0.12	0.56	0.24	1.92
ECTRP04	Aug-97	3.13	3.04	0.15	0.58	0.26	2.03
ECTRP05	Aug-97	3.27	3.17	0.19	0.62	0.19	2.18
ECTRP06	Aug-97	4.06	3.96	0.26	0.62	0.16	2.31
Combined	Aug-97	10.88	10.76	1.49	0.60	0.12	2.71
ECTRP01	Sep-97	3.62	3.52	0.20	0.60	0.19	2.19
ECTRP03	Sep-97	2.70	2.61	0.12	0.56	0.24	1.92
ECTRP04	Sep-97	3.13	3.04	0.15	0.58	0.26	2.03
ECTRP05	Sep-97	3.27	3.17	0.19	0.62	0.19	2.18
ECTRP06	Sep-97	4.06	3.96	0.26	0.62	0.16	2.31
Combined	Sep-97	6.59	6.52	0.10	0.27	0.50	1.22
ECTRP01	Oct-97	6.43	6.31	0.86	0.46	0.32	1.82
ECTRP03	Oct-97	5.23	5.11	0.66	0.52	0.25	1.98
ECTRP04	Oct-97	4.77	4.65	0.56	0.52	0.24	1.92
ECTRP05	Oct-97	4.61	4.49	0.57	0.48	0.35	1.77
ECTRP06	Oct-97	5.25	5.13	0.72	0.50	0.27	1.89
Combined	Oct-97	11.00	10.90	0.74	0.52	0.19	2.43
ECTRP01	May-98	1.77	1.68	0.11	0.57	0.27	1.66
ECTRP02	May-98	1.41	1.32	0.07	0.43	0.52	1.16
ECTRP04	May-98	1.12	1.01	0.08	0.55	0.34	1.33
ECTRP05	May-98	1.80	1.70	0.12	0.51	0.37	1.47
ECTRP06	May-98	2.01	1.91	0.11	0.54	0.37	1.63
Combined	May-98	3.29	3.20	0.10	0.62	0.17	2.28
ECTRP01	Jun-98	2.07	1.97	0.20	0.50	0.42	1.47
ECTRP03	Jun-98	2.42	2.32	0.17	0.39	0.57	1.23
ECTRP04	Jun-98	2.74	2.63	0.23	0.51	0.41	1.65
ECTRP05	Jun-98	2.31	2.22	0.13	0.44	0.51	1.38
ECTRP06	Jun-98	2.24	2.13	0.19	0.43	0.52	1.31
Combined	Jun-98	3.96	3.87	0.15	0.41	0.49	1.55
ECTRP01	Aug-98	3.62	3.52	0.20	0.60	0.19	2.19
ECTRP03	Aug-98	2.70	2.61	0.12	0.56	0.24	1.92
ECTRP04	Aug-98	3.13	3.04	0.15	0.58	0.26	2.03
ECTRP05	Aug-98	3.27	3.17	0.19	0.62	0.19	2.18
ECTRP06	Aug-98	4.06	3.96	0.26	0.62	0.16	2.31
Combined	Aug-98	5.38	5.30	0.14	0.19	0.20	0.78
ECTRP01	Sep-98	2.60	2.51	0.09	0.60	0.21	2.04
ECTRP03	Sep-98	2.71	2.61	0.18	0.65	0.22	2.13
ECTRP04	Sep-98	3.57	3.47	0.23	0.61	0.17	2.20
ECTRP05	Sep-98	2.71	2.63	0.10	0.58	0.22	1.99
ECTRP06	Sep-98	1.90	1.81	0.07	0.57	0.27	1.77
Combined	Sep-98	4.31	4.23	0.09	0.11	0.22	0.43

Combined - calculation of index combining all pond data collected during the sampling event.

Table 4-9
Peters Pond Phase II 1997 - 1998 Phytoplankton Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECPTP01	Aug-97	5.23	5.09	0.93	0.64	0.21	2.35
ECPTP02	Aug-97	5.94	5.81	1.09	0.69	0.16	2.61
ECPTP03	Aug-97	5.78	5.65	1.04	0.60	0.26	2.25
ECPTP04	Aug-97	4.70	4.57	0.78	0.64	0.19	2.28
ECPTP05	Aug-97	6.76	6.63	1.17	0.54	0.29	2.13
Combined	Aug-97	11.86	11.75	1.14	0.67	0.11	3.12
ECPTP01	Sep-97	5.11	4.98	0.69	0.32	0.71	1.21
ECPTP02	Sep-97	5.37	5.25	0.73	0.34	0.67	1.27
ECPTP03	Sep-97	4.95	4.83	0.65	0.44	0.44	1.62
ECPTP04	Sep-97	5.60	5.48	0.76	0.40	0.58	1.52
ECPTP05	Sep-97	5.68	5.54	1.04	0.56	0.43	2.08
Combined	Sep-97	15.24	15.14	1.15	0.50	0.30	2.49
ECPTP01	Oct-97	5.11	4.98	0.69	0.32	0.71	1.21
ECPTP02	Oct-97	5.37	5.25	0.73	0.34	0.67	1.27
ECPTP03	Oct-97	4.95	4.83	0.65	0.44	0.44	1.62
ECPTP04	Oct-97	5.60	5.48	0.76	0.40	0.58	1.52
ECPTP05	Oct-97	5.68	5.54	1.04	0.56	0.43	2.08
Combined	Oct-97	15.24	15.14	1.15	0.50	0.30	2.49
ECPTP01	May-98	4.07	3.95	0.57	0.67	0.19	2.33
ECPTP02	May-98	3.26	3.15	0.38	0.64	0.25	2.12
ECPTP03	May-98	4.13	4.01	0.55	0.69	0.19	2.43
ECPTP04	May-98	3.94	3.81	0.55	0.65	0.23	2.26
ECPTP05	May-98	3.32	3.21	0.33	0.57	0.31	1.93
Combined	May-98	5.45	5.35	0.35	0.58	0.24	2.34
ECPTP01	Jun-98	1.05	0.96	0.06	0.30	0.70	0.71
ECPTP02	Jun-98	1.15	1.05	0.09	0.27	0.75	0.65
ECPTP03	Jun-98	1.98	1.89	0.10	0.47	0.40	1.43
ECPTP04	Jun-98	1.69	1.59	0.09	0.43	0.48	1.24
ECPTP05	Jun-98	1.74	1.64	0.10	0.39	0.49	1.13
Combined	Jun-98	2.99	2.91	0.09	0.35	0.52	1.24
ECPTP01	Aug-98	3.11	3.02	0.17	0.63	0.17	2.21
ECPTP02	Aug-98	3.53	3.43	0.25	0.58	0.23	2.05
ECPTP03	Aug-98	4.05	3.95	0.32	0.57	0.23	2.09
ECPTP04	Aug-98	3.18	3.08	0.24	0.60	0.21	2.07
ECPTP05	Aug-98	2.30	2.19	0.18	0.58	0.25	1.79
Combined	Aug-98	5.96	5.87	0.21	0.20	0.18	0.83
ECPTP01	Sep-98	3.48	3.38	0.23	0.71	0.11	2.53
ECPTP02	Sep-98	3.12	3.01	0.28	0.62	0.25	2.09
ECPTP03	Sep-98	3.55	3.45	0.28	0.69	0.12	2.44
ECPTP04	Sep-98	3.16	3.07	0.18	0.69	0.12	2.40
ECPTP05	Sep-98	2.38	2.29	0.13	0.72	0.14	2.32
Combined	Sep-98	5.65	5.57	0.19	0.64	0.09	2.69

Combined - calculation of index combining all pond data collected during the sampling event.

Table 4-10
Summary of Phase II 1997-1998
Phytoplankton Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
Peters Pond	August '97	11.86	11.75	1.14	0.67	0.11	3.12
Snake Pond		9.01	8.90	0.76	0.78	0.15	3.47
Triangle Pond		10.88	10.76	1.49	0.60	0.12	2.71
Peters Pond	September '97	15.24	15.14	1.15	0.50	0.30	2.49
Snake Pond		5.82	5.71	0.49	0.28	0.37	1.13
Triangle Pond		6.59	6.52	0.10	0.27	0.50	1.22
Peters Pond	October '97	15.24	15.14	1.15	0.50	0.30	2.49
Snake Pond		11.18	11.07	0.96	0.53	0.13	2.45
Triangle Pond		11.00	10.90	0.74	0.52	0.19	2.43
Peters Pond	May '98	5.45	5.35	0.35	0.58	0.24	2.34
Snake Pond		3.73	3.64	0.17	0.43	0.44	1.61
Triangle Pond		3.29	3.20	0.10	0.62	0.17	2.28
Peters Pond	June '98	2.99	2.91	0.09	0.35	0.52	1.24
Snake Pond		4.06	3.97	0.14	0.42	0.41	1.61
Triangle Pond		3.96	3.87	0.15	0.41	0.49	1.55
Peters Pond	August '98	5.96	5.87	0.21	0.20	0.18	0.83
Snake Pond		4.33	4.24	0.19	0.66	0.13	2.54
Triangle Pond		5.38	5.30	0.14	0.19	0.20	0.78
Peters Pond	September '98	5.65	5.57	0.19	0.64	0.09	2.69
Snake Pond		5.02	4.93	0.18	0.60	0.15	2.43
Triangle Pond		4.31	4.23	0.09	0.11	0.22	0.43

Table 4-11
Peters Pond Phase II 1997 - 1998 Zooplankton Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECPTP01	Aug-97	0.81	0.65	0.23	0.48	0.51	0.78
ECPTP02	Aug-97	0.83	0.69	0.16	0.53	0.50	0.95
ECPTP03	Aug-97	0.94	0.78	0.25	0.61	0.42	1.09
ECPTP04	Aug-97	0.71	0.57	0.15	0.56	0.53	0.90
ECPTP05	Aug-97	1.07	0.92	0.27	0.48	0.50	0.93
Combined	Aug-97	0.96	0.84	0.12	0.53	0.44	1.10
ECPTP01	Sep-97	0.92	0.79	0.16	0.47	0.48	0.91
ECPTP02	Sep-97	1.62	1.46	0.46	0.44	0.56	1.01
ECPTP03	Sep-97	0.98	0.84	0.20	0.41	0.65	0.79
ECPTP04	Sep-97	0.86	0.71	0.18	0.85	0.27	1.52
ECPTP05	Sep-97	1.07	0.93	0.19	0.58	0.40	1.21
Combined	Sep-97	1.36	1.25	0.15	0.51	0.42	1.28
ECPTP01	Oct-97	0.50	0.38	0.07	0.34	0.78	0.47
ECPTP02	Oct-97	0.96	0.82	0.18	0.42	0.65	0.82
ECPTP03	Oct-97	0.61	0.46	0.15	0.46	0.69	0.64
ECPTP04	Oct-97	0.63	0.51	0.10	0.38	0.70	0.61
ECPTP05	Oct-97	0.68	0.55	0.13	0.60	0.53	0.97
Combined	Oct-97	0.77	0.66	0.07	0.36	0.68	0.70
ECPTP01	May-98	1.81	1.61	0.75	0.68	0.31	1.50
ECPTP02	May-98	1.37	1.22	0.34	0.70	0.28	1.53
ECPTP03	May-98	1.43	1.25	0.48	0.75	0.27	1.55
ECPTP04	May-98	1.92	1.76	0.53	0.77	0.19	1.90
ECPTP05	May-98	2.05	1.88	0.64	0.55	0.38	1.38
Combined	May-98	2.50	2.37	0.42	0.65	0.20	1.91
ECPTP01	Jun-98	1.75	1.57	0.57	0.83	0.18	1.91
ECPTP02	Jun-98	2.27	2.09	0.74	0.80	0.17	2.05
ECPTP03	Jun-98	1.49	1.33	0.44	0.92	0.14	2.03
ECPTP04	Jun-98	2.25	2.10	0.54	0.82	0.13	2.21
ECPTP05	Jun-98	1.61	1.43	0.55	0.80	0.23	1.76
Combined	Jun-98	2.36	2.23	0.40	0.79	0.12	2.29
ECPTP01	Aug-98	2.41	2.24	0.77	0.82	0.15	2.18
ECPTP02	Aug-98	1.85	1.66	0.67	0.77	0.22	1.77
ECPTP03	Aug-98	1.87	1.72	0.49	0.72	0.20	1.78
ECPTP04	Aug-98	2.62	2.43	0.97	0.72	0.22	1.91
ECPTP05	Aug-98	2.39	2.21	0.86	0.80	0.16	2.05
Combined	Aug-98	3.12	2.98	0.57	0.76	0.12	2.38
ECPTP01	Sep-98	1.71	1.52	0.65	0.76	0.23	1.66
ECPTP02	Sep-98	2.65	2.48	0.89	0.72	0.20	1.96
ECPTP03	Sep-98	2.45	2.27	0.80	0.71	0.21	1.87
ECPTP04	Sep-98	3.14	2.96	1.14	0.74	0.19	2.09
ECPTP05	Sep-98	2.54	2.36	0.89	0.75	0.18	1.99
Combined	Sep-98	2.80	2.66	0.57	0.75	0.14	2.24

Combined - calculation of index combining all pond data collected during the sampling event.

Table 4-12
Snake Pond Phase II 1997 - 1998 Zooplankton Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECSNP02	Aug-97	NA	NA	NA	NA	NA	NA
ECSNP03	Aug-97	NA	NA	NA	NA	NA	NA
ECSNP06	Aug-97	NA	NA	NA	NA	NA	NA
ECSNP07	Aug-97	1.43	1.23	0.60	0.62	0.36	1.20
ECSNP08	Aug-97	0.88	0.73	0.20	0.53	0.45	0.96
Combined	Aug-97	9.12	8.39	1.39	0.12	0.54	0.52
ECSNP02	Sep-97	0.66	0.53	0.11	0.54	0.55	0.88
ECSNP03	Sep-97	0.76	0.64	0.12	0.45	0.62	0.81
ECSNP06	Sep-97	0.94	0.80	0.17	0.68	0.33	1.32
ECSNP07	Sep-97	2.44	2.24	1.03	0.73	0.23	1.80
ECSNP08	Sep-97	1.18	1.05	0.20	0.39	0.56	0.87
Combined	Sep-97	1.88	1.77	0.19	0.38	0.50	1.09
ECSNP02	Oct-97	1.12	0.93	0.41	0.36	0.69	0.64
ECSNP03	Oct-97	0.93	0.79	0.16	0.24	0.81	0.46
ECSNP06	Oct-97	0.54	0.40	0.10	0.43	0.69	0.59
ECSNP07	Oct-97	0.80	0.64	0.22	0.42	0.61	0.68
ECSNP08	Oct-97	0.57	0.43	0.12	0.33	0.74	0.46
Combined	Oct-97	0.93	0.81	0.11	0.29	0.72	0.61
ECSNP02	May-98	0.81	0.65	0.23	0.42	0.58	0.67
ECSNP03	May-98	0.80	0.64	0.22	0.49	0.49	0.79
ECSNP06	May-98	0.86	0.69	0.27	0.57	0.46	0.92
ECSNP07	May-98	1.45	1.24	0.62	0.38	0.69	0.75
ECSNP08	May-98	0.60	0.40	0.25	0.29	0.85	0.32
Combined	May-98	1.36	1.22	0.25	0.50	0.39	1.15
ECSNP02	Jun-98	1.47	1.29	0.53	0.80	0.23	1.66
ECSNP03	Jun-98	2.33	2.15	0.80	0.64	0.27	1.64
ECSNP06	Jun-98	NA	NA	NA	NA	NA	NA
ECSNP07	Jun-98	1.63	1.45	0.57	0.53	0.44	1.17
ECSNP08	Jun-98	1.68	1.49	0.62	0.81	0.20	1.78
Combined	Jun-98	2.55	2.40	0.52	0.62	0.21	1.79
ECSNP02	Aug-98	1.61	1.45	0.45	0.66	0.26	1.52
ECSNP03	Aug-98	1.62	1.46	0.46	0.76	0.21	1.76
ECSNP06	Aug-98	1.75	1.58	0.58	0.85	0.18	1.96
ECSNP07	Aug-98	1.41	1.25	0.37	0.38	0.65	0.83
ECSNP08	Aug-98	1.30	1.15	0.28	0.36	0.64	0.78
Combined	Aug-98	1.75	1.63	0.26	0.60	0.32	1.59
ECSNP02	Sep-98	2.21	2.04	0.69	0.73	0.20	1.87
ECSNP03	Sep-98	2.07	1.89	0.78	0.74	0.23	1.76
ECSNP06	Sep-98	2.06	1.89	0.65	0.61	0.33	1.51
ECSNP07	Sep-98	1.73	1.56	0.56	0.57	0.36	1.31
ECSNP08	Sep-98	1.37	1.20	0.43	0.45	0.55	0.94
Combined	Sep-98	2.72	2.58	0.51	0.59	0.23	1.78

Combined - calculation of index combining all pond data collected during the sampling event.

NA - not available (sample bottles broken in shipment)

Table 4-13
Triangle Pond Phase II 1997 - 1998 Zooplankton Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECTRP01	Aug-97	NA	NA	NA	NA	NA	NA
ECTRP03	Aug-97	0.86	0.71	0.18	0.47	0.5	0.84
ECTRP04	Aug-97	0.62	0.47	0.16	0.51	0.62	0.7
ECTRP05	Aug-97	1.05	0.92	0.18	0.33	0.66	0.69
ECTRP06	Aug-97	1.28	1.12	0.35	0.50	0.42	1.04
Combined	Aug-97	1.08	0.96	0.14	0.39	0.51	0.87
ECTRP01	Sep-97	0.57	0.43	0.12	0.62	0.47	0.86
ECTRP03	Sep-97	0.97	0.84	0.13	0.39	0.60	0.80
ECTRP04	Sep-97	0.53	0.40	0.09	0.46	0.69	0.64
ECTRP05	Sep-97	0.55	0.41	0.10	0.70	0.46	0.97
ECTRP06	Sep-97	0.47	0.36	0.06	0.60	0.54	0.83
Combined	Sep-97	0.84	0.74	0.07	0.42	0.55	0.86
ECTRP01	Oct-97	0.63	0.50	0.09	0.44	0.63	0.70
ECTRP03	Oct-97	0.59	0.47	0.07	0.48	0.61	0.78
ECTRP04	Oct-97	0.77	0.66	0.07	0.50	0.49	0.98
ECTRP05	Oct-97	0.78	0.66	0.08	0.46	0.47	0.90
ECTRP06	Oct-97	0.77	0.66	0.07	0.55	0.44	1.08
Combined	Oct-97	0.77	0.67	0.04	0.52	0.41	1.07
ECTRP01	May-98	0.86	0.69	0.28	0.78	0.34	1.25
ECTRP03	May-98	1.86	1.68	0.68	0.77	0.19	1.78
ECTRP04	May-98	1.19	0.99	0.48	0.74	0.30	1.32
ECTRP05	May-98	0.97	0.83	0.19	0.42	0.59	0.83
ECTRP06	May-98	1.38	1.21	0.44	0.83	0.21	1.72
Combined	May-98	1.92	1.80	0.30	0.54	0.36	1.47
ECTRP01	Jun-98	1.41	1.26	0.37	0.47	0.43	1.03
ECTRP03	Jun-98	1.89	1.75	0.42	0.59	0.32	1.51
ECTRP04	Jun-98	1.21	1.04	0.39	0.51	0.49	1.00
ECTRP05	Jun-98	1.95	1.79	0.56	0.61	0.32	1.51
ECTRP06	Jun-98	1.38	1.21	0.44	0.46	0.55	0.95
Combined	Jun-98	2.28	2.16	0.35	0.47	0.38	1.35
ECTRP01	Aug-98	1.41	1.25	0.37	0.66	0.28	1.44
ECTRP03	Aug-98	2.02	1.85	0.61	0.73	0.19	1.82
ECTRP04	Aug-98	1.41	1.24	0.47	0.78	0.25	1.63
ECTRP05	Aug-98	1.46	1.30	0.41	0.74	0.28	1.64
ECTRP06	Aug-98	1.41	1.23	0.47	0.71	0.34	1.48
Combined	Aug-98	2.23	2.10	0.38	0.75	0.14	2.12
ECTRP01	Sep-98	1.28	1.12	0.35	0.56	0.45	1.16
ECTRP03	Sep-98	2.03	1.87	0.53	0.51	0.48	1.30
ECTRP04	Sep-98	2.09	1.90	0.80	0.62	0.34	1.49
ECTRP05	Sep-98	2.38	2.21	0.74	0.78	0.17	2.05
ECTRP06	Sep-98	2.18	2.01	0.66	0.66	0.28	1.70
Combined	Sep-98	2.49	2.36	0.42	0.71	0.17	2.09

Combined - calculation of index combining all pond data collected during the sampling event.
NA - not available (sample broken in shipment)

Table 4-14
Summary of Phase II 1997-1998
Zooplankton Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
Peters Pond	August '97	0.96	0.84	0.12	0.53	0.44	1.10
Snake Pond		9.12	8.39	1.39	0.12	0.54	0.52
Triangle Pond		1.08	0.96	0.14	0.39	0.51	0.87
Peters Pond	September '97	1.36	1.25	0.15	0.51	0.42	1.28
Snake Pond		1.88	1.77	0.19	0.38	0.50	1.09
Triangle Pond		0.84	0.74	0.07	0.42	0.55	0.86
Peters Pond	October '97	0.77	0.66	0.07	0.36	0.66	0.70
Snake Pond		0.93	0.81	0.11	0.29	0.72	0.61
Triangle Pond		0.77	0.67	0.04	0.52	0.41	1.07
Peters Pond	May '98	2.50	2.37	0.42	0.65	0.20	1.91
Snake Pond		1.36	1.22	0.25	0.50	0.39	1.15
Triangle Pond		1.92	1.80	0.30	0.54	0.36	1.47
Peters Pond	June '98	2.36	2.23	0.40	0.79	0.12	2.29
Snake Pond		2.55	2.40	0.52	0.62	0.21	1.79
Triangle Pond		2.28	2.16	0.35	0.47	0.38	1.35
Peters Pond	August '98	3.12	2.98	0.57	0.76	0.12	2.38
Snake Pond		1.75	1.63	0.26	0.60	0.32	1.59
Triangle Pond		2.23	2.10	0.38	0.75	0.14	2.12
Peters Pond	September '98	2.80	2.66	0.57	0.75	0.14	2.24
Snake Pond		2.72	2.58	0.51	0.59	0.23	1.78
Triangle Pond		2.49	2.36	0.42	0.71	0.17	2.09

Table 4-15
Peters Pond Phase II June and September 1998 Benthic Macroinvertebrate Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECPTP01	Jun-98	4.28	4.04	2.20	0.90	0.08	2.59
ECPTP02	Jun-98	2.16	1.92	1.13	0.73	0.25	1.61
ECPTP03	Jun-98	2.82	2.47	1.94	0.88	0.14	1.84
ECPTP05	Jun-98	3.53	3.23	2.19	0.90	0.10	2.23
ECPTP06	Jun-98	4.68	4.48	1.97	0.63	0.28	1.98
ECPTP07	Jun-98	3.54	3.36	1.19	0.48	0.34	1.45
ECPTP08	Jun-98	5.17	4.95	2.35	0.73	0.18	2.30
ECPTP09	Jun-98	2.69	2.50	1.04	0.59	0.34	1.56
ECPTP10	Jun-98	4.39	4.20	1.67	0.02	0.00	0.06
ECPTP11	Jun-98	2.40	1.92	1.77	0.04	0.00	0.06
Combined	Jun-98	10.31	10.16	2.19	0.62	0.15	2.63
ECPTP01	Sep-98	2.57	2.31	1.43	0.75	0.22	1.73
ECPTP02	Sep-98	2.01	1.61	1.44	0.88	0.21	1.42
ECPTP03	Sep-98	2.05	1.82	1.00	0.83	0.18	1.82
ECPTP05	Sep-98	2.74	2.56	0.97	0.37	0.67	1.01
ECPTP06	Sep-98	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled
ECPTP07	Sep-98	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled
ECPTP08	Sep-98	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled
ECPTP09	Sep-98	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled	Not Sampled
ECPTP10	Sep-98	2.23	1.95	1.33	0.88	0.15	1.84
ECPTP11	Sep-98	1.84	1.61	0.91	0.42	0.64	0.87
Combined	Sep-98	4.35	4.19	1.21	0.51	0.39	1.69

Combined - calculation of index combining all pond data collected during the sampling event.

Not Sampled - samples not collected due to rocky substrate

Table 4-16

Triangle Pond Phase II June and September 1998 Benthic Macroinvertebrate Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECTRP01	Jun-98	3.48	3.21	2.01	0.72	0.26	1.84
ECTRP02	Jun-98	4.22	3.97	2.27	0.86	0.10	2.45
ECTRP03	Jun-98	3.46	3.17	2.12	0.84	0.14	2.09
ECTRP04	Jun-98	3.20	2.96	1.71	0.82	0.15	2.10
ECTRP06	Jun-98	3.11	2.80	2.00	0.90	0.11	2.08
ECTRP10	Jun-98	5.33	5.09	2.79	0.87	0.08	2.70
ECTRP11	Jun-98	5.01	4.76	2.72	0.82	0.12	2.44
ECTRP12	Jun-98	2.52	2.20	1.63	0.66	0.39	1.37
ECTRP13	Jun-98	2.69	2.42	1.56	0.79	0.22	1.81
ECTRP14	Jun-98	2.53	2.25	1.52	0.69	0.34	1.51
Combined	Jun-98	9.07	8.91	2.66	0.75	0.10	3.02
ECTRP01	Sep-98	2.30	2.04	1.27	0.82	0.19	1.81
ECTRP02	Sep-98	1.66	1.45	0.72	0.54	0.44	1.12
ECTRP03	Sep-98	1.85	1.62	0.92	0.54	0.43	1.12
ECTRP04	Sep-98	1.75	1.46	1.08	0.75	0.32	1.34
ECTRP05	Sep-98	0.62	0.00	0.45	Undefined	1.00	0.00
ECTRP06	Sep-98	2.49	1.86	1.79	0.96	0.10	1.33
ECTRP10	Sep-98	3.45	3.20	1.84	0.84	0.13	2.21
ECTRP11	Sep-98	1.89	1.57	1.22	0.80	0.27	1.44
ECTRP12	Sep-98	2.56	2.33	1.29	0.75	0.22	1.81
ECTRP13	Sep-98	2.24	2.02	1.08	0.69	0.31	1.60
ECTRP14	Sep-98	1.51	1.29	0.69	0.48	0.45	0.93
Combined	Sep-98	3.56	3.41	0.91	0.57	0.28	1.80

Combined - calculation of index combining all pond data collected during the sampling event.

Table 4-17
Snake Pond Phase II June and September 1998 Benthic Macroinvertebrate Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
ECSNP02	Jun-98	2.73	2.43	1.73	0.86	0.16	1.89
ECSNP03	Jun-98	1.54	1.35	0.59	0.14	0.90	0.29
ECSNP06	Jun-98	1.31	0.99	0.87	0.41	0.73	0.57
ECSNP07	Jun-98	5.22	4.96	2.95	0.84	0.11	2.52
ECSNP08	Jun-98	4.76	4.51	2.59	0.88	0.09	2.58
ECSNP12	Jun-98	2.01	1.61	1.44	0.84	0.24	1.35
ECSNP13	Jun-98	3.82	3.56	2.10	0.72	0.27	1.94
ECSNP14	Jun-98	2.06	1.54	1.51	0.83	0.29	1.15
ECSNP15	Jun-98	2.35	2.14	1.06	0.47	0.54	1.12
ECSNP16	Jun-98	4.26	4.05	1.92	0.58	0.37	1.74
Combined	Jun-98	8.56	8.41	2.22	0.49	0.39	1.98
ECSNP02	Sep-98	NA	NA	NA	NA	NA	NA
ECSNP03	Sep-98	0.63	0.42	0.28	0.35	0.80	0.38
ECSNP06	Sep-98	0.44	0.22	0.20	0.29	0.90	0.20
ECSNP07	Sep-98	1.44	0.72	1.00	1.00	0.33	0.69
ECSNP08	Sep-98	2.27	2.04	1.10	0.68	0.27	1.57
ECSNP12	Sep-98	1.86	1.60	1.07	0.59	0.47	1.15
ECSNP13	Sep-98	2.50	2.09	1.81	0.96	0.11	1.72
ECSNP14	Sep-98	1.43	1.14	0.87	0.64	0.40	1.03
ECSNP15	Sep-98	2.63	2.30	1.75	0.78	0.25	1.62
ECSNP16	Sep-98	0.75	0.50	0.41	0.23	0.89	0.25
Combined	Sep-98	3.10	2.93	0.88	0.40	0.55	1.18

Combined - calculation of index combining all pond data collected during the sampling event.

NA - sample not available due to breakage during shipment to laboratory

Table 4-18
Summary of Phase II 1998 Benthic Macroinvertebrate Diversity Indices

		Richness Indices			Evenness Index	Diversity Indices	
Location	Date	Gleason's Index	Margalef's Index	Menhinick's Index	Evenness Index	Simpson's Index	Shannon's Index
Peters Pond	June '98	10.31	10.16	2.19	0.62	0.15	2.63
Snake Pond		8.56	8.41	2.22	0.49	0.39	1.98
Triangle Pond		9.07	8.91	2.66	0.75	0.10	3.02
Peters Pond	August '98	4.35	4.19	1.21	0.51	0.39	1.69
Snake Pond		3.10	2.93	0.88	0.40	0.55	1.18
Triangle Pond		3.56	3.41	0.91	0.57	0.28	1.80

Table 4-19
FS-12 Treatment System Monitoring
Biota

Surface Water Tests Phase I	Study		Reference		Tests			Two Sample Tests				
Tier II Parameter	n	mean	n	mean	Omnibus Normality	Modified Levene Equal Variance	Test	Probability Level	Result	Difference	Ecological Criteria Guideline	Ecological Criteria Guideline Exceedence
chlorophyll *a* (µg/L)	27	2.83	40	2.42	Reject	Cannot Reject	Wilcoxon Rank-Sum	0.582	Accept Ho	14.5%	> 20%	No
benthic invertebrates (organisms/cm^2)	12	0.502	17	0.581	Reject	Cannot Reject	Wilcoxon Rank-Sum	0.521	Accept Ho	15.7%	> 20%	No

Surface Water Tests Phase II	Study		Reference		Tests			Two Sample Tests				
Tier II Parameter	n	mean	n	mean	Omnibus Normality	Modified Levene Equal Variance	Test	Probability Level	Result	Difference	Ecological Criteria Guideline	Ecological Criteria Guideline Exceedence
chlorophyll *a* (µg/L)	30	2.87	61	2.16	Reject	Cannot Reject	Equal variance test	0.007	Reject Ho	24.7%	> 20%	Yes
benthic invertebrates (organisms/cm^2)	19	0.244	37	0.307	Cannot Reject	Cannot Reject	Equal variance test	0.379	Accept Ho	25.8%	> 20%	Yes

%=percent
Ho=null hypothesis
n=number of observations
sd =standard deviation
µg/L = micrograms per liter
organisms/cm^2 = organisms per square centimeter

Table 4-20
FS12 Surface Water
Analysis of Variance Results
Biota

	chlorophyll a (µg/L)			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Class				0.30%
Reference	2.87	125	none	
Study	2.59	71	none	
Season				2.84%
Spring	3.28	51	Summer	
Summer	2.33	88	Spring	
Fall	2.99	57	none	
Phase				0.66%
Phase I	2.54	86	none	
Phase II	2.94	110	none	
Limnion				12.6%
epilimnion	2.39	165	hypolimnion	
hypolimnion	4.77	31	epilimnion	

	Benthic Invertebrates (microorganisms/cm^2)			
	mean	n	Fisher's LSD Different than	Contribution to Total Variance %
Class				0.003%
Reference	0.393	54	none	
Study	0.343	31	none	
Season				35.3%
Spring	0.305	30	Summer	
Summer	1.15	10	Fall, Spring	
Fall	0.251	45	Summer	
Phase				6.83%
Phase I	0.548	29	II	
Phase II	0.286	56	I	

LSD = Least Significant Difference
n = number of observations
µg/L = micrograms per liter
organisms/cm^2 = organisms per square centimeter

Table 5-1
Summary of Parameters for Trophic State Analyses
May Through November 1998

	Potentially Impacted Pond	Reference Ponds	
Trophic State Parameter	**Snake Pond**	**Triangle Pond**	**Peters Pond**
Physical Data			
Secchi Disk Depth	3.5 m (11.5 ft) - 6.6 m (21.5 ft)	2.7 m (8.8 ft) - 4.5 m (14.8 ft)	3.5 m (11.5 ft) - 6.6 m (21.5 ft)
Nutrient Data			
Total Phosphorus	1.5 - 24.5 µg/L	0.62 - 10.0 µg/L	0.62 - 10.0 µg/L
Biological Data			
Chlorophyll *a*	1.1 - 6.5 µg/L	0.4 - 4.0 µg/L	0.6 - 5.4 µg/L
Algal Concentration	7,005 cells/mL	23,321 cells/mL	10,862 cells/mL
Dominant Algal Genera (September 1998)	Cyanophyta	Cyanophyta	Cyanophyta

m = meters

µg/L = micrograms per liter

cells/ml = cells per milliliter

ft = feet

Table 5-2
Summary of Trophic State Analyses for Snake, Triangle, and Peters Ponds

		Range of Trophic State Indices			Trophic State of Pond Based on Trophic State Indices		
Ecosystem	Sampling Events	TSI(TP)	TSI(Cha)	TSI(SD)	Total Phosphorus	Chlorophyll a	Secchi Disk Depth
Snake Pond	July-August 1996	NA	NA	33 - 35	NA	NA	mesotrophic
	July 1997	47 - 73	32 - 36	36 - 38	mesotrophic -eutrophic	mesotrophic	mesotrophic
	August 1997	27 - 69	35 - 38	40 - 41	oligo-mesotrophic - eutrophic	mesotrophic	mesotrophic
	September 1997	39 -56	31 - 43	36 - 42	mesotrophic	mesotrophic	mesotrophic
	August 1998	15 - 40	37 - 42	41 - 42	oligotrophic - mesotrophic	mesotrophic	mesotrophic
	September 1998	21 - 34	40 - 46	38 - 40	oligo-mesotrophic -mesotrophic	mesotrophic	mesotrophic
	May - November 1998	10 - 50	31 - 49	34 - 42	oligotrophic - meso-eutrophic	mesotrophic	mesotrophic
Triangle Pond	July-August 1996	NA	35	NA	NA	mesotrophic	NA
	July 1997	49 - 86	41 - 49	36 - 41	mesotrophic -eutrophic	mesotrophic	mesotrophic
	August 1997	27 - 47	36 - 38	36 - 40	oligo-mesotrophic - eutrophic	mesotrophic	mesotrophic
	September 1997	37 - 96	22 - 34	38 - 40	mesotrophic -eutrophic	oligo-mesotrophic -mesotrophic	mesotrophic
	August 1998	-3 - 23	31 - 36	40 - 43	oligotrophic - oligo-mesotrophic	mesotrophic	mesotrophic
	September 1998	9 - 26	34 - 37	42 - 45	oligotrophic - oligo-mesotrophic	mesotrophic	mesotrophic
	May - November 1998	-3 - 37	22 - 44	38 - 46	oligotrophic - mesotrophic	oligo-mesotrophic - mesotrophic	mesotrophic
Peters Pond	July-August 1996	NA	NA	NA	NA	NA	NA
	July 1997	27 - 52	34 - 40	38 - 43	oligo-mesotrophic -mesotrophic	mesotrophic	mesotrophic
	August 1997	27 - 47	33 - 40	38 - 43	oligo-mesotrophic - mesotrophic	mesotrophic	mesotrophic
	September 1997	49 - 61	36 - 38	33 - 38	mesotrophic -eutrophic	mesotrophic	mesotrophic
	August 1998	-3 - 24	26 - 47	36 - 40	oligotrophic - oligo-mesotrophic	oligo-mesotrophic -mesotrophic	mesotrophic
	September 1998	14 - 24	38 - 40	34 - 37	oligotrophic - oligo-mesotrophic	mesotrophic	mesotrophic
	May - November 1998	-3 - 37	26 - 47	33 - 42	oligotrophic - mesotrophic	oligo-mesotrophic - mesotrophic	mesotrophic

Cha = chloraphyll *a* TP = total phosphorus SD = Secchi depth
NA = not available TSI = trophic state index

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9 December 1999

Mr. Jim F. Snyder
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SUBJECT: Contract F41624-97-D-8006
MMR Plume Response Program
DO 0015 DCN/PROJECT # AFC-J23-35S18901-M21-0010
Final Fuel Spill-12 Treatment System 1998 Annual Ecological Assessment Report

Dear Mr. Snyder:

As directed by the Air Force Center for Environmental Excellence, Jacobs Engineering Group Inc. is hereby providing 22 bound copies, one unbound copy, and one electronic copy of the above referenced document, dated December 1999. Copies are also being sent to the appropriate agencies.

Please feel free to contact me or Lisa Allinger at (508) 564-5746 extension 312, if you have any questions or comments.

Sincerely,

Eric W. Banks, P. E.
Program Manager

EWB/ac

Enclosures: Document (23 & 1 EDD)

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